1994-09

Contribution of digitized communications to the Extended Close Battlefield

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	September 1994	Master's Thesis

4. TITLE AND SUBTITLE
CONTRIBUTION OF DIGITIZED COMMUNICATIONS TO THE EXTENDED CLOSE BATTLEFIELD (U)

5. FUNDING NUMBERS

6. AUTHOR(S)
Pound, David S.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey, CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release, distribution is unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

This thesis develops a robust analytical computer simulation model of the Extended Close Battlefield (ECB) to examine the performance of the command, control and communications (C^3) systems of the Extended Fiber Optic Guided Missile (EFOGM), using both digitized and non-digitized communications. The ECB is represented by a 24 state Semi-Markov chain formulation. It contains transient and absorbing states that the simulation models using Monte Carlo processes and probablistic time distributions. The primary measure of effectiveness (MOE) used for comparison between the digitized and non-digitized systems is the total time required to process a call for fire (CFF). Sensitivity analysis is performed to compare the amount of time a CFF spends in a queue, waiting to be processed, within the non-digitized system over a variable range of available targets. Additional sensitivity analysis is performed by adjusting the input time parameters of the probablistic time distributions to replicate the stress of continuous combat operations. While the amount of time a CFF spends in a queue can be brought to zero for specific numbers of available targets, the digitized system outperforms the non-digitized system over all ranges of available targets, using both standard and increased values of input time parameters.

14. SUBJECT TERMS
Simulation Model, Stochastic Process, Extended Close Battlefield, Extended Fiber Optic Guided Missile, Rapid Force Projection Initiative

15. NUMBER OF PAGES
125

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

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CONTRIBUTION OF DIGITIZED COMMUNICATIONS TO THE EXTENDED CLOSE BATTELFIELD

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Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
September 1994

Thesis
P75287
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This thesis develops a robust analytical computer simulation model of the Extended Close Battlefield (ECB) to examine the performance of the command, control and communications (C^3) systems of the Extended Fiber Optic Guided Missile (EFOGM), using both digitized and non-digitized communications. The ECB is represented by a 24 state Semi-Markov chain formulation. It contains transient and absorbing states that the simulation models using Monte Carlo processes and probablistic time distributions. The primary measure of effectiveness (MOE) used for comparison between the digitized and non-digitized systems is the total time required to process a call for fire (CFF). Sensitivity analysis is performed to compare the amount of time a CFF spends in a queue, waiting to be processed, within the non-digitized system over a variable range of available targets. Additional sensitivity analysis is performed by adjusting the input time parameters of the probablistic time distributions to replicate the stress of continuous combat operations. While the amount of time a CFF spends in a queue can be brought to zero for specific numbers of available targets, the digitized system outperforms the non-digitized system over all ranges of available targets, using both standard and increased values of input time parameters.

THESIS DISCLAIMER

The reader is cautioned that computer programs developed in this thesis may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

Additionally, a portion of the analysis conducted for this thesis was performed using *APL2/PC* and *AGSS*. Naval Postgraduate School uses this program under a test agreement with IBM Research.

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EXECUTIVE SUMMARY

The Rapid Force Projection Initiative (RFPI) is a study sponsored by the Dismounted Battlespace Battle Laboratory (DBBL) located at Fort Benning, Georgia. The capabilities to be demonstrated through the RFPI are those that will enable the maneuver commander to engage enemy forces before the enemy can engage him in the Close Battle. Specifically, RFPI is to provide new capabilities within the 5 to 15 kilometer band of the battlefield known as the Extended Close Battlefield (ECB). The significance of these capabilities to the dismounted soldier is in the improvement of supporting sensors, command, control and communications (C^3) devices, and non-line-of-sight (NLOS) weapons. These new capabilities will enable friendly commanders to significantly reduce enemy combat power before U.S. soldiers are involved in the direct fire battle. One of the NLOS weapon systems proposed under the RFPI is the Enhanced Fiber Optic Guided Missile (EFOGM).

EFOGM is a fiber optic guided missile capable of engaging and destroying enemy weapon systems at extended ranges. The system can engage targets within a full 360 degree radius from its battery location. The missile is a top attack round that allows the gunner to adjust the missile's trajectory up to the point of impact, and is guided through a fiber optic data link. The data link connects the missile's seeker head to a console at the gunner's station. This NLOS weapon greatly improves the ability of ground force commanders to influence the ECB by destroying high value enemy targets before the enemy has a chance to execute a coordinated, synchronized attack.

Since EFOGM is a NLOS system, it must depend primarily upon forward placed observers and sensors to provide target information. The EFOGM targeting system will be integrated into the Advanced Field Artillery Tactical Data System (AFATDS), which will allow rapid transmission of target data from the observer/sensor to the battery using digitized communications. This will permit parallel processing of targeting information versus the current series processing inherent in voice communications. It is logical to assume that the expeditious delivery of target information would enhance the ability of the EFOGM to prosecute targets. With a digitized C^3 system, a sensor or scout could simultaneously burst transmit target information, using pre-formatted reports, to all headquarters requiring target information, as well as the firing battery. The data could then be simultaneously processed for firing at all locations. Current voice C^3 systems require the observer/sensor report to be relayed through a series of single processing nodes. Each node must quickly process target information and pass it to the next node in the series, until it ultimately becomes firing data as an approved mission at the battery level.

The objective of this thesis is to determine the impact of a digitized C^3 system versus a non-digitized C^3 system concerning target prosecution with the EFOGM. Specifically, it addresses the question of whether a digitized communication system is more effective in handling EFOGM targeting and target prosecution than a voice system. This study uses a computer simulation model to examine the performance characteristics of the voice and digitized fire control network for the EFOGM. The approach used in building the computer model is to take current procedures for calling indirect fires on targets, and apply them to the employment of the EFOGM within the context of the computer simulation model.

By executing a large number of replications of the simulation model, values for EFOGM call-for-fire (CFF) processing times and the time those CFFs waited for processing are collected. With data from simulation runs of both the digitized and non-digitized C^3 systems, operating ranges for the two systems are obtained. For each run, the specific time events occur are recorded for use in data analysis. These events are included for both the digitized and non-digitized replications, and each is recorded for specific targets and observers. To compare and contrast the differences between the digitized and non-digitized systems, total CFF processing times are calculated by taking the difference between the time a target was detected and the time the EFOGM battery finishes processing the CFF. Additionally, to test the hypothesis that CFF processing times would increase under the stress of continuous combat operations, values for input time parameters are increased by 25% and the replications executed again.

Examining the data from the output of the simulation replications, it was discovered that the digitized system is superior to the non-digitized regardless of the number of targets presented in a replication. Additionally, if the number of missiles available to the battery is increased, re-shoots of targets are more prevalent. These additional missiles cause an increase in the number of CFFs processed by both the digitized and non-digitized C^3 systems. While the increase in numbers of CFFs processed has a significant effect on the CFF processing times for the non-digitized system, only a slight increase was noticed in the CFF processing times for the digitized system. Finally, the stress of continuous combat operations was modeled through a 25% increase in selected processing times. While this caused a disproportionate increase in the non-digitized CFF processing times, processing times for the digitized system remained relatively proportional to the 25% increase in selected times.

This thesis demonstrates the potential of relatively simple, computer simulation models to estimate performance parameters in undeveloped combat systems. This information can provide analytic agencies with the ability to incorporate future technologies into existing combat models, or be used alone for data analysis. Ultimately, it provides valuable information for defense planers to preparation for future operations and missions around the world.

I. INTRODUCTION

A. BACKGROUND

Changes in the Department of Defense (DOD) caused by the lessening of tensions in Eastern Europe and the lessons learned from Operations Just Cause and Desert Storm (ODS) have resulted in DOD budgets being significantly smaller than previous years. Additionally, the lessons of ODS have shown that the early deployable land forces need more capable and lethal equipment, and lighter and more easily deployable medium to heavy force equipment. As a result, the DOD's Science and Technology (S&T) program was established to affordably produce and field new military systems that are more robust, but also provide more "bang for the buck". To support these goals and to prioritize the S&T program, the DOD established seven S&T "Thrusts" so the highest priority current deficiencies could be fixed. Specifically, Thrust Five, Advanced Land Combat, is focused to provide new technology for land forces in close combat. Thrust Five consists of three top level demonstrations of technology and hardware specific to:

- Advanced Vehicle Technologies
- Rapid Force Projection Initiative (RFPI)
- 21st Century Land Warrior

Specifically, the goal of the RFPI is to investigate technologies concerned with lethality, survivability and deployability to provide improved warfighting capabilities for a force projection Army.

B. RFPI

The Rapid Force Projection Initiative (RFPI) is sponsored by the Dismounted Battlespace Battle Laboratory (DBBL), Fort Benning, Georgia. The capabilities to be demonstrated through the RFPI are those that will enable the maneuver commander to engage enemy forces before the enemy can engage him in the Close Battlefield. (The

Close Battlefield is that portion of the battlefield reaching from zero to five kilometers in front of the foxhole.) Specifically, these initiatives are to provide new capabilities within the 5 to 15 kilometer band of the battlefield known as the Extended Close Battlefield (ECB). This is especially critical when considering the composition of our light, highly deployable forces. The significance of RFPI to the dismounted soldier is in the improvement of supporting sensors, command control and communications (C^3) devices, and non-line-of-sight (NLOS) weapons that will enable friendly commanders to significantly reduce enemy combat power before his soldiers are involved in the direct fire battle. One of the NLOS weapon systems proposed under the RFPI is the Enhanced Fiber Optic Guided Missile (EFOGM).

C. BASIC DESCRIPTION OF EFOGM

EFOGM is a fiber optic guided missile capable of engaging and destroying camouflaged, dug-in, moving or defiladed targets at extended ranges. The system can engage targets within a full 360 degree radius from its battery location. The missile is a top attack round that allows the gunner to adjust the missile's trajectory up to the point of impact, and is guided through a fiber optic data link. The data link connects the missile's seeker head to a console at the gunner's station, which also allows the gunner to scan the target area and select targets. This NLOS weapon greatly improves the ability of ground force commanders to influence the ECB by destroying high value enemy targets before the enemy has a chance to execute a coordinated, cohesive attack.

1. Employment

Since EFOGM is a NLOS system, it must depend primarily upon forward placed observers/sensors to provide target information. The EFOGM targeting system will be integrated into the Advanced Field Artillery Tactical Data System (AFATDS) allowing for rapid transmission of target data from observer/sensor to shooter through the use of digitized communications. The target data are rapidly processed and sent to the gunner's console, where the gunner will select a route for the missile to fly to the target. Once firing confirmation is received, the gunner will launch and track the flight plan until the missile reaches the target area. At that point, the gunner can manually guide the missile on to the target, or "lock-on" the target and take control of another missile. Some of the characteristics of the EFOGM are given in Table 1.

Maximum Missile Range	15 Kilometers
Minimum Missile Range	1 Kilometer
Time of Flight	10 seconds per Kilometer (100 m/s)
Rate of Fire	2 missiles within 30 seconds
Number of On-board Missiles	Six or more
Mobility	Equal to a High Mobility Multi-Purpose Wheeled Vehicle (HMMWV)
Sustainability	96 hours continuous
Crew Size	Two men

Table 1. EFOGM Required Characteristics

2. Targets

Targets for the EFOGM can be both pre-planned and targets of opportunity. Due to the long range and precision of the EFOGM, it will be possible to engage a variety of high value targets while the enemy is still in march formation, or before moving into the effective range of his weapons during an attack. Examples of high value targets are enemy command and control assets (C^2), air defense assets (ADA), engineering assets (ENG), artillery pieces and prime movers, helicopters and selected armored vehicles. Since there are only a limited number of EFOGMs available within a rapidly deploying force, it will *NOT* be used as a mass armor killing system.

3. Command and Control (C^2)

The EFOGM is a divisional asset that is fought at the brigade level. The EFOGM company will consist of three platoons of four squads. Target acquisition is provided through the Fire Support Element (FSE) located with the brigade tactical operations center (TOC) to an EFOGM liaison officer (LNO). The EFOGM liaison element consists of a section leader (normally the EFOGM battery commander) and two target analysts.

The fires of the EFOGM company are coordinated by the brigade Fire Support Officer (FSO), who passes targeting information and engagement orders through the EFOGM liaison element. The EFOGM LNO then passes firing orders to the EFOGM battery. EFOGM platoon headquarters (HQ) directs which squad will execute the fire mission to reduce the chance of target duplication. With the introduction of digitized communications, targeting information can be sent simultaneously to the brigade FSO, EFOGM LNO and the firing battery to reduce engagement time.

4. Target Acquisition

Assets that acquire targets for the EFOGM range from those at the national level to those in front line combat units. These could include human intelligence (HUMINT) reports generated from units in contact, reports from such platforms as the Unmanned Aerial Vehicles (UAV), the future scout vehicle with enhanced sensor arrays, or ground surveillance radars (GSR). Additionally, the EFOGM can be used to gather intelligence and information using its video seeker head while enroute to targets.

5. Target Processing and Allocation

All target information, regardless of source, is ultimately processed at the brigade TOC by the brigade FSO. Allocation of EFOGMs to targets is made in support of the brigade commander's intent and is coordinated through the EFOGM LNO in the TOC, who prepares and coordinates EFOGM battery fires.

D. DIGITIZED COMMUNICATIONS

There has been much attention focused on the potential benefits of digital communication systems on the battlefield. Digitized communication permits parallel processing of targeting information versus the current series processing inherent in voice communications. It is logical to assume that the expeditious delivery of target information would enhance the ability of the EFOGM to prosecute targets. Likewise, any delays in transmitting target information could increase the possibility that the target will not be in the field-of-view of the seeker when the missile reaches the target area.

With a digitized communication system, a sensor or scout can burst transmit target information through a pre-formatted Size-Activity-Location-Uniform-Time-Equipment (SALUTE) report. The assistance of Global Positioning Systems (GPS), laser range finders, and improved frequency hopping Single Channel Ground and Airborne Radios (SINCGARS) enhances the accuracy and delivery potential of these forward located observer/sensors. As mentioned, information can arrive simultaneously at the division ready brigade (DRB) TOC, EFOGM LNO, and the firing battery location. The data would automatically be processed for firing at all locations. Using a "do not fire by exception" policy, the target will be fired unless told not to by the DRB HQ. Current voice C^3 systems require the observer/sensor report to be relayed through a series of single nodes, which must quickly process the information and pass it on to the next node in the series, before it ultimately becomes firing data in an approved mission at the firing unit level. Handling of multiple or simultaneous fire missions is not possible, so fire missions may have to wait valuable time to be processed at each level of control, thereby reducing the number of targets that may be engaged in a time period.

E. STATEMENT OF THE PROBLEM

There is little information available concerning the benefits of digitized communication in terms of normal measures of combat effectiveness. Current high resolution wargaming models such as JANUS and CASTFOREM do not adequately model delays caused by the processing of calls for fire (CFF) generated by forward observers or scouts. The objective of this thesis is to determine the impact of a digitized versus non-digitized communication system with respect to target prosecution with the EFOGM. Specifically, how much more effective is a digitized communication system in handling EFOGM targeting and target prosecution versus the currently available voice system? These results may help determine whether a digitized communication system, coupled with the EFOGM, will significantly improve the lethality and survivability of deployable forces; specifically, the division ready brigade (DRB). Intuitively, one would expect that a decrease in the target prosecution time would result in more missiles fired over a similar period of time. Additionally, the chances of a EFOGM being "successful" (i.e., striking a desired target) should improve because of the increased time the EFOGM has to acquire a target in the engagement area.

F. SCOPE

The DBBL has developed a high resolution scenario (HRS) in JANUS that replicates a DRB in a forced entry operation in Latin America (HRS 33.5). This HRS is the foundation for the friendly and enemy force compositions and scenario used in this study. Using a state space representation of the HRS, a simple, highly robust computer model has been developed to provide a range of values for target prosecution times. These values can be input into current high resolution simulation models to replicate the delays caused by call for fire (CFF) processing.

This study will use a discrete time analytical combat simulation model to examine the performance characteristics of the voice and digitized fire control network for the EFOGM missile. The combat environment in which the EFOGM operates will be modeled as a Semi-Markov process with transient and absorbing states, combining a Monte Carlo process within the simulation to model the events of acquiring, processing, and prosecuting targets by the EFOGM. The approach used in building the state space description was to take current procedures for calling indirect fire on targets, apply them to the employment of the EFOGM and model these steps as states in a state space diagram. The description of this state space is shown in the following chapter.

G. STUDY LIMITATIONS AND ASSUMPTIONS

While this study will seek to closely replicate engagements by the EFGOM on targets in the ECB, there are certain aspects of the ECB that were not, or could not be covered by the simulation model that must be noted. (See Appendix A for a depiction of the ECB used in the simulation.) These assumptions and limitations include:

- Transition probabilities to and from certain states within the state space diagram are based solely on the author's professional judgment. Since the EFGOM is a proposed weapon system, detection, performance and survivability data are not currently available.

- Forward Observer (FO)/Sensor performance is not based on any technical data. No thermal or image intensification devices were modeled. It is only assumed that the FO/Sensor has a finite range (10 km) in which it can detect targets, and a defined sector of scan.

- The FO will attempt to establish communications with BDE or AFATDS to pass a CFF message only a limited number of times. After a defined number of attempts, he will drop the acquired target, and go back to searching and try to establish communications upon his next acquisition. This assumption is based on professional experience that would indicate that a FO would not stop doing his mission (scanning the battlefield for targets) just because he could not contact his higher headquarters.

- High value targets are assumed to be traveling in march column to the location of U.S. forces at a uniform rate of march, regardless of any terrain considerations. Additionally, the vehicles are dispersed in the march column in exact doctrinal distances between vehicles, platoons, companies, battalions, regiments, etc. This march column is based on the march column in HRS 33.5.

- Once a target has be acquired by a FO, the FO is able to track that target throughout the engagement, and will not CFF on that target again.

- All targets will enter the main battle area by traversing through a single EFOGM engagement area (EA). The five sensors are arranged around the EA such that three are placed on the leading edge of the EA and two are in depth 3 km behind the leading edge of the EA.

- EFOGM batteries are assumed to be located so that the distance from the battery to the leading edge of the EA is the maximum range of the EFGOM. Additionally, all EFOGM fires are considered to have come from a single "super-battery", and not from tactically dispersed, individual gun systems controlled through a battery or platoon headquarters unit.

- The C^3 node located at BDE or AFATDS is able to track the continuous location of a targeted high value target. This prevents multiple CFFs from being processed on the same target. Since the number of high value targets is limited within the array of all targets, the ability to track this location is feasible.

- While the digitized scenario depicted by CSC does not include a mission confirmation of the AFATD's CFF, it is assumed that at a minimum, BDE will pass a mission confirmation and a "Fire/Hold Fire" command to subordinate elements to be echoed down the chain of command. Without this consideration, a CFF feasibly could reach the battery, and not the BDE or PL, and be processed for firing by the battery. Since "silence equals consent" in the CSC model, the battery would assume that the lack of any acknowledgment from BDE meant to execute the mission, when in fact, it could be because BDE never received the mission. Considering the amount of attention focused on fratricide in today's Army, it is illogical to think confirmation would not ever be required.

- Missile damage is not a function of target vehicle type, but purely a function of a Monte Carlo draw.

- Missile rates of fire are not considered. Since all guns are consolidated into one "super-battery" simultaneous or near simultaneous launches may occur.

- Shoot downs of EFOGM missiles while in flight, or EFOGMs that become erratic and lost in flight (LIF) are assumed to occur at a time value equal to one half of the total time of flight of the missile to the intended target.

- No re-supply occurs during the battle. The EFOGM battery fights with only its original basic load of missiles. Considering possible scenarios for early entry forces, this is a distinct possibility.

- For simulation purposes, the lead element is located 9 kilometers from the leading edge of the EFOGM EA at the start of the simulation. This allows for the earliest possible acquisition of targets in the simulation.

II. STATE SPACE DESCRIPTION

A. THE EXTENDED CLOSE BATTLEFIELD

To study the effects of the EFOGM on the Extended Close Battlefield (ECB), a description of events that occur in that area of the battlefield is necessary. A description of those battlefield events could be considered as a collection of random variables *X(t)*, where *X(t)* is the *state* of the battlefield at time *t*. This description of the battlefield can be considered a stochastic process, where the state space of that stochastic process is defined as the set of all possible values that the random variable could assume. A definition of the stochastic process is provided in *Introduction to Probability Models* by Sheldon M. Ross.

> . . . consider a stochastic process $\{X_n, n = 0, 1, 2, \ldots\}$ that takes on a finite or countable number of possible values. Unless otherwise mentioned, this set of possible values of the process will be denoted by the set of non-negative integers $\{0, 1, 2, \ldots\}$. If $X_n = i$, then the process is said to be in state i at time n. We suppose that whenever the process is in state i, there is a fixed probability P_{ij} that it will next be in state j. That is we suppose that
>
> $$P\{X_{n+1} = j \mid X_n = i, X_{n-1} = i_{n-1}, \ldots, X_1 = i_1, X_0 = i_0\} = P_{ij} \qquad (1)$$
>
> for all states $i_0, i_1, \ldots, i_{n-1}, i, j$ and all $n \geq 0$. Such a stochastic process is known as a *Markov Chain*. Equation (1.1) may be interpreted as stating that, for a Markov chain, the conditional distribution of any future state X_{n+1} given the past states $X_0, X_1, \ldots, X_{n-1}$ and the present state X_n, is independent of the past states and depends on the present state. [Ref. 10, p. 135]

Note that for a discrete time Markov chain, transition times are all one time step. This particular Markov chain refers to a process with stationary probabilities of transition (i.e., the probability of transitioning from one state to another is not a function of the previous state, time, range or any other factor). Such a description of the ECB could be used, but it would not account for such factors as ranges to targets that are critical when considering missile engagements. Therefore, the classical Markovian approach can not be used since state space transition probabilities and sojourn times are functions of previous states and do not posses the memoryless property, therefore prohibiting a closed form solution. Likewise, a continuous time Markov Chain would be inappropriate since the conditional distribution of a future state given the current state and past states depends only on the present state, and is independent of the past. This would not be appropriate, for example, in a state that describes the processing of a call for fire (CFF). CFF processing is dependent on when the CFF was initiated, which is a past event. However, the notion of a Semi-Markov process can be used to generalize the ECB state space. Again from Ross:

> Suppose that a process can be in any one of N states $1, 2, \ldots, N$, and that each time it enters state i it remains there for a random amount of time having mean μ_i and then makes a transition into state j with probability P_{ij}. Such a process is called a *Semi-Markov process.* [Ref. 20, p. 325]

For the state space description of the ECB, the Semi-Markov notions of the probability of transitioning from one state to another (P_{ij}'s), the transition (sojourn) times from state to state (T_{ij}'s), absorbing states, total number of visits to specific states, and the proportion of time that the model spends in a particular state i (P_i) will be used to develop measures of effectiveness within the state space description.

B. STATE SPACE INTERPRETATION

1. General

The state space used in this thesis replicates the area in the ECB where FOs are positioned to provide targeting information to the controlling DRB headquarters. For the purposes of this thesis, an FO represents any and all types of information gathering systems from ground emplaced sensors, radars, airborne platforms and scout vehicles to dismounted forward observers. It consists of $j + 24$ states, where j is defined as the number of high value targets determined to be present in an attacking enemy force. What follows is a description of each state, the explanation of transition probabilities from that state, and how sojourn times are determined for that state. A graphical depiction of the state space is shown in Figure 1.

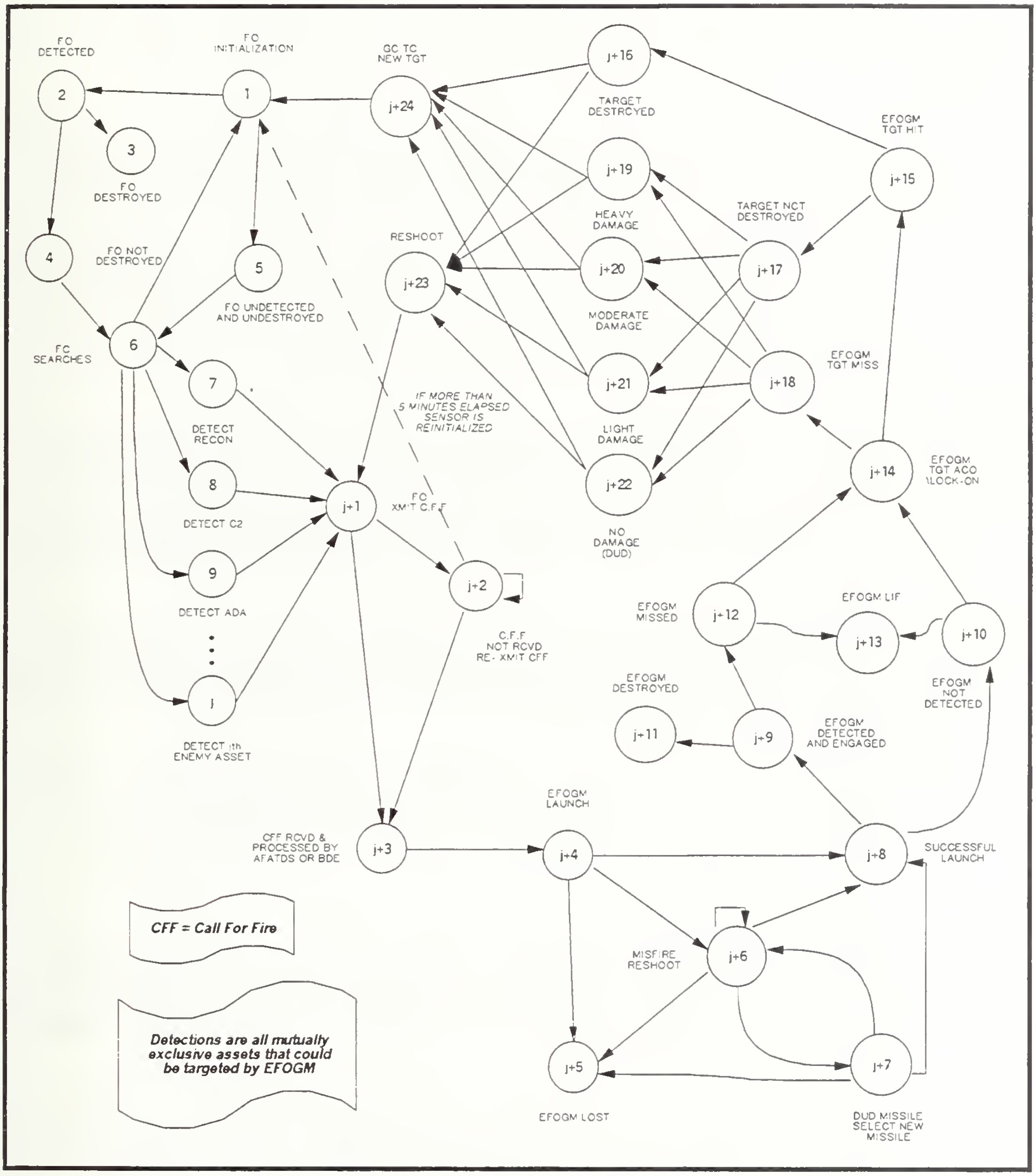

Figure 1. State Space Diagram

2. Sensor States

States One through *j* describe the FO scanning the battlefield, acquiring targets, and the possible detection and destruction of the FO by the enemy. The description of each state is:

- State One - FO Initialization. In State One the FO is "initialized" or brought to life. Each FO has a maximum visibility range and scans a sector based upon user defined scan arcs and fields of view (FOV) based upon the notion of the Cartioid Distribution [Ref. 4, p. 80]. The observer/FO may transition to either State Two (FO Detected) or State Three (FO Undetected / Not Destroyed). It is assumed there is no time needed for transition from initialization to searching, and that the chance of detection by enemy forces remains constant throughout the simulation.

- State Two - FO Detected. In State Two, enemy forces have detected the FO. The FO may transition from State Two to State Three (FO Destroyed - an absorbing state) or State Four (FO Detected|Engaged but Not Destroyed). It is assumed that once detection is made, the FO completes the CFF and is then destroyed.

- State Three - FO Destroyed. State Three is an absorbing state that describes the detection of the FO by enemy forces and its subsequent destruction. There is no transition from State Three.

- State Four - FO Detected|Engaged but Not Destroyed. State Four is a transit node from State Two (FO Detected) to State Six (FO Searches). The transition probability is 1.0 (if not destroyed the FO will search), and the transition time is 0.0.

- State Five - FO Undetected and Not Destroyed. State Five is a transit node from State One (FO Initialization) to State Six (FO Searches). The transition probability is 1.0 (if undetected and not destroyed the FO will search), and the transition time is 0.0.

- State Six - FO Searches. In State Six the FO begins its search of the battlefield for high value targets within its FOV. Should it detect a high value target, it will transition to the specific detection state (7 through *j*) with probability 1.0. The sojourn time from the search state is a function of a detection algorithm. However, if the FO fails to detect a target within a time limit, it transitions back to State One with a transition time equal to the time limit. This transition possibility provides for a continuous probability that the FO could be detected throughout the simulated battle. This is a realistic depiction of the searching that occurs on the battlefield by both friendly and enemy forces.

- States 7 through j - Detect High Value Target. States 7 through j describe the detection of a specific high value target by an FO. Each state will transition to state $j + 1$ (Transmit a Call for Fire) with zero sojourn time and probability 1.0 *if detection occurs for that specific target.* Once a target is detected, it is assumed the FO will immediately call for fire (CFF) on the detected target

States $j + 1$ through $j + 11$ describe the action of the FO transmitting a CFF to the DRB TOC to launch of the EFOGM:

- State $j + 1$ - Transmit Call for Fire (CFF). State $j + 1$ describes the FO transmitting a CFF on the detected target. There is a chance that his CFF will not be received at the DRB HQ or the AFATDS (State $j + 2$) or that the DRB HQ/AFATDS will receive the CFF and begin processing the mission (State $j + 3$). The sojourn time in state $j + 1$ is negligible. Either radio contact is made immediately, and transition is made to state $j + 3$, or the FO fails to make contact and transition is made to state $j + 2$.

- State $j + 2$ - CFF Not Received/Re-Transmit CFF. Should the FO fail to make contact with the DRB HQ/AFATDS, he will continue to attempt communications for a period of time before abandoning the attempt, returning to search for other targets (a return to State One). It is assumed that each attempt to re-contact the DRB HQ/AFATDS will take approximately five seconds. Should contact be made, the process continues to State $j + 3$ (CFF Received/Processing Begins).

- State $j + 3$ - CFF Received and Processed at DRB S2/FSO Cell or at AFATDS. State $j + 3$ accounts for the largest portion of time consumed in the state diagram. The probability of transitioning from this state to State $j + 4$ (EFOGM Launch) depends on the time required to process the CFF from the FO.

3. Processing States

A specific discussion of the time required to process the CFF depends on the scenario that is being replicated. Specifically, there is a different logical process for the two types of C^3 systems. Processing for both the digitized and non-digitized systems will now be discussed. (Since the user decides to execute either a non-digitized or digitized scenario, there is a duplication of states $j + 3a$ through $j + 3f$.)

a. Non-Digitized Processing

States $j + 3a$ through $j + 3f$ depict the non-digitized processing of the CFF. These states depict the expanded version of the single state $j+3$ shown in Figure 1. The states are depicted in Figure 2, and will now be discussed in detail.

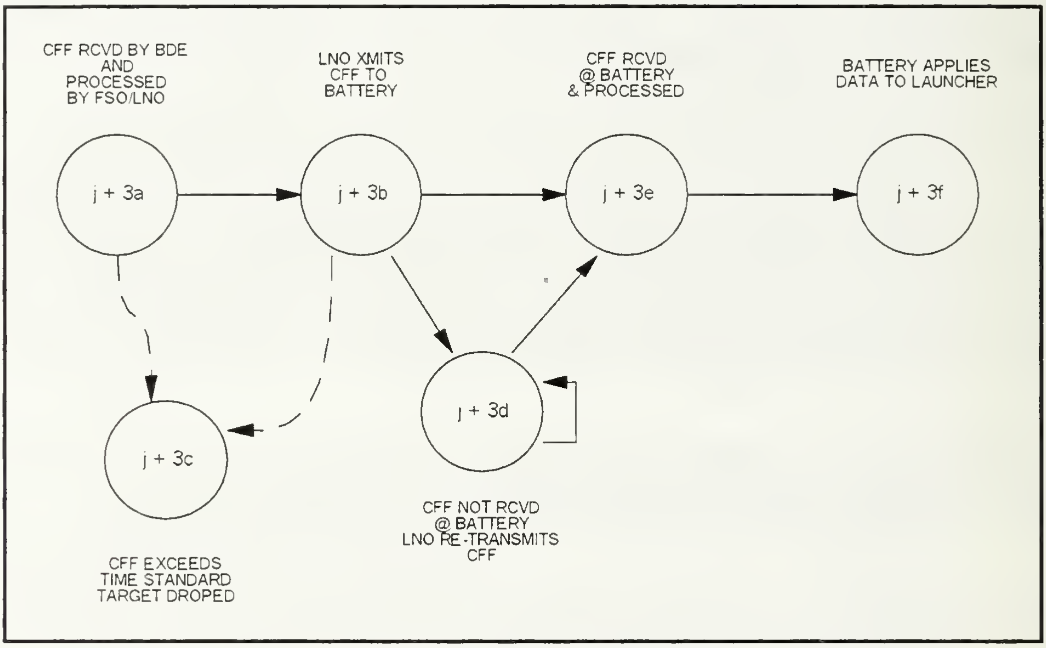

Figure 2. Non-Digitized Processing Sub-State Space

- <u>State $j + 3a$ - CFF Received and Processed at DRB S2/FSO Cell</u>. Time begins when the FO transmits the first CFF to the DRB HQ. There a radio telephone operator (RTO) must stop or finish any job he is currently working on, record the CFF, and decide what action is needed. The target must then be passed to the brigade fire support element (FSE). This process takes a varying amount of time, depending on the nature of the target. If either the brigade fire support officer (FSO), or fire support non-commissioned officer (FSNCO) is not busy with other fire missions, then they will process the mission immediately. If busy, the target data are "queued", and will be rechecked when either is free and all previously "queued" target information is processed. The FSO, or FSNCO then decides if the target is a valid EFOGM target according to the brigade commander's intent. Once the target is processed, it is delivered to the EFOGM liaison officer (LNO) for processing. If the LNO is not immediately available, again the target data are queued and will be checked when the LNO is free.

Should the total processing time from the beginning of the FO's CFF to the beginning of the LNO's processing exceed a maximum allowed time, the target may be dropped. For example, targets moving at 5.55 meters per second can travel over two kilometers in six minutes. Since additional processing time will continue to accumulate after the target is sent to the LNO, this may seriously decrease the EFOGM probability of target acquisition in the engagement area. Should this occur, States $j + 3a$ or $j + 3b$ could transition into State $j + 3c$ (Excess Process Time), which is an absorbing state. If not, the EFOGM LNO verifies the mission, determines which EFOGM asset will fire the mission, prepares the launch order and attempts to pass the fire mission by FM radio to the EFOGM battery (State j + 3e). In reality, the LNO would also determine the number of launchers and number of missiles to be fired for the mission. However, for purposes of this simulation, it is assumed that only one missile will be fired per target, and there is only one consolidated battery containing all missiles.

- <u>State j + 3b - Transmit Fire Mission to EFOGM Battery</u>. Similar to State j + 1, this state represents the LNO attempting to pass the fire mission to the EFOGM battery over FM voice radio. The transmission may be received (State j + 3e), or not received and must be tried again (State j + 3d). Time Accumulation is the same as State j + 1.

- <u>State j + 3c - Excess Process Time</u>. State j + 3c is an absorbing state describing a CFF that has required too much time to process, and is dropped from consideration.

- <u>State j + 3d - CFF Not Received/Re-transmit CFF</u>. Same as State j + 2, however, should total processing time exceed a set standard, the target will be dropped and a transition into State j + 5 occurs.

- <u>State j + 3e - CFF Received at EFOGM Battery/Battery Processing</u>. In State j + 3e, the battery platoon leader has received the fire mission from the LNO, and begins processing the fire mission. The platoon leader determines the aim point and missile way point, based on the terrain, target range, and target rate of march. Once the platoon leader projects an intercept zone, he prepares the fire mission and issues the launch order to the firing squads.

- <u>State j + 3f - Battery Applies Data to Launcher</u>. As data arrive at the launcher, the gunner inputs the data into the launch computer and executes the launch command. The cumulative processing time becomes the sojourn time to State $j + 4$ (EFOGM Launch).

b. *Digitized Processing*

States $j + 3a$ through $j + 3l$ depict the digitized processing of a CFF. These states depict the expanded version of the single state $j+3$ shown in Figure 1. The states are shown in Figure 3, and will now be discussed in detail.

- State $j + 3a$ - CFF Received and Processed by AFATDS. Once the target is received by AFATDS, it compares the target to the target priority, assets available to fire and the brigade commander's plan. It computes which units should fire, and the number of missiles for the mission. It then simultaneously passes the CFF to the BDE FSE, the platoon leader and the battery.

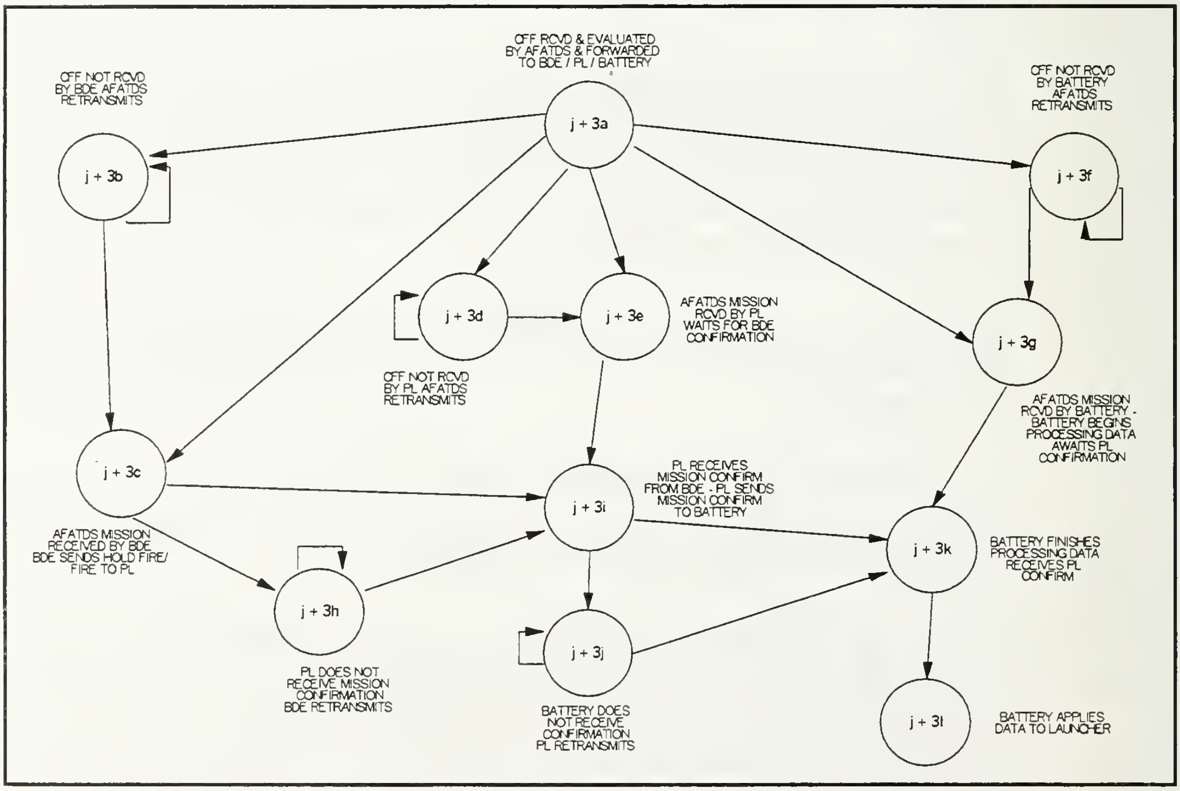

Figure 3. Digitized Processing Sub-State Space

- States $j + 3b/d/f$ - CFF not received by BDE/PL/Battery - AFATDS re-transmits. In these three states the CFF transmitted by AFATDS was not received by some or all of the receiving units. AFATDS will continue to attempt the transmission until contact is made.

- State *j + 3c* - AFATDS mission received by brigade. Once the mission arrives at the brigade level, it is checked to ensure that an acceptable firing solution was reached by AFATDS. While the CSC report states that "silence equals consent", it is felt that such a hands-off approach to engagements is unlikely, especially with the growing fratricide concerns within today's armed forces. Therefore, in this state space depiction, brigade confirms the mission and passes a "Fire" or "Hold-Fire" to the platoon leader.

- State *j + 3e* - AFATDS mission received by PL. The platoon leader has received the mission specifics from the AFATDS and awaits the command from BDE to hold fire or fire the mission.

- State *j + 3g* - AFATDS mission received by battery. Once the mission arrives from AFATDS, the battery immediately begins processing the data into a firing solution. The battery waits until the fire command is echoed by the platoon leader to the battery to apply the firing data to the launcher.

- State *j + 3h* - Mission confirmation not received by PL. Similar to States *j + 3b/d/f*, BDE will continue attempting the transmission until contact is made with the PL.

- State *j + 3i* - PL receives mission confirmation from BDE. Once the PL receives the mission confirmation from BDE, he immediately passes the "Fire" or "Hold-Fire" command to the battery.

- State *j + 3j* - Mission confirmation not received by Battery. Similar to State *j + 3h*, the PL will continue attempting the transmission until contact is made with the battery.

- State *j + 3k* - Battery completes mission data processing. In this state the battery has finished transferring mission data to the system and selecting and validating the missile's route to the target. The battery waits here for mission confirmation from the PL.

- State *j + 3l* - Battery applies data to the launcher. Once the PL's confirmation arrives, the gun applies the data to the launcher, and executes the launch command.

3. Missile Launch States

States $j + 4$ through $j + 8$ describe the possible occurrences at missile launch, and are described as follows:.

- State $j + 4$ - EFOGM Launch. State $j + 4$ describes the gunner executing the launch command (i.e., "pulling the trigger"). State $j + 4$ can transition into one of three states: $j + 8$ (Successful Launch), $j + 6$ (Misfire/Re-shoot) or $j + 5$ (EFOGM Lost). There is no time involved with any of these transitions.

- State $j + 5$ - EFOGM Lost. This is an absorbing state describing a missile that leaves the launcher and fails to follow launch commands (e.g., an erratic round).

- State $j + 6$ - Misfire/Re-shoot. State $j + 6$ describes a missile that fails to leave the launcher once the launch command has been executed. There are misfire procedures which the gunner must follow, and these account for the transition times from this state to four other possible states: $j + 5$ (EFOGM Lost), $j + 7$ (Dud Missile/New Missile selected), $j + 8$ (Successful Launch), or the state can transition back into itself.

- State $j + 7$ - Dud Missile/New Missile Selected. Should a missile continue to misfire, it may in fact be a dud round that will not fire. Should this occur, a new missile will be selected for launch and the gunner will "pull the trigger" for that missile. The time needed to select a new missile and apply launch data is the transition time from this state to states $j + 4$, $j + 5$ or $j + 8$. Again, transition probabilities are defined by the user.

- State $j + 8$ - Successful Launch. This state describes the missile that has left the launcher and is flying properly. This state concludes the launch states and transitions to the flight states of $j + 9$ (EFOGM Detected in Flight/Engaged). and $j + 10$ (EFOGM Undetected in Flight). The transition time for missile flight time is not considered from this state.

4. Missile Flight and Impact

States $j + 9$ through $j + 16$, describe possible events during the flight of missile, impact of the missile on the target, or failure of the missile to impact on the target, and have the following criteria:

- State $j + 9$ - EFOGM Detected and Engaged. Within this state the EFOGM missile has been detected and engaged by enemy forces. Destruction of the missile causes a transition into State $j + 11$ (EFOGM Destroyed), while failure of the enemy to destroy the missile transitions the process into State $j + 12$ (EFOGM Missed by Enemy). The only calculated transition time would be from $j + 9$ to $j + 11$, that is estimated to occur at one half of the missile's flight time to the target.

- State $j + 10$ - EFOGM Undetected in Flight. This state indicates that the missile has not been detected in route to its target. However, it could become erratic during flight and be "lost" (State $j + 13$). If this does not occur, the state space transitions to State $j + 14$ (EFOGM Target Acquisition/Lock On). No transition times between states are considered here unless the missile is lost in flight, which is estimated to occur at one half of the flight time to the target.

- State $j + 11$ - EFOGM Destroyed. This is an absorbing state describing the destruction of the EFOGM by enemy forces.

- State $j + 12$ - EFOGM Missed by Enemy. This state represents an enemy failure to destroy the EFOGM in flight. The missile may now acquire and lock onto an enemy target (State $j + 13$), or become lost in flight (State $j + 12$). Transition time is calculated only if the missile becomes lost in flight. This transition time is estimated as one half the time of flight to the target.

- State $j + 13$ - EFOGM Lost in Flight. This is an absorbing state describing a missile, in flight to a target, that becomes erratic or has a malfunction that causes it to fly improperly, and become lost. This is assumed to occur at a time equal to one half the time of flight of the missile to the intended target.

- State $j + 14$ - EFOGM Target Acquisition/Lock On. At this point, the EFOGM has "tipped over" so that its seeker head is looking into the target area and has acquired/locked on to a target vehicle. The missile can either impact on the target (State $j + 15$), or miss the target (State $j + 18$). Transition time from State $j + 14$ to either $j + 15$, or $j + 18$ is equal to the time of flight of the missile to the target.

- State $j + 15$ - EFOGM Impact. In this state, the missile has impacted on the target vehicle. There are two possible transitions from this state: either the missile causes catastrophic destruction of the target (State $j + 18$), or the target is not destroyed upon impact (State $j + 17$). There is no transition time from this state to either state $j + 17$ or $j + 18$.

- State j + 16 - EFOGM Misses the Target. The missile has failed to impact the target in this state. However, it is assumed that despite a failure to impact on the target, there is a possibility of some collateral damage due to the explosion of the warhead if the missile lands close enough to the target. Transition time from this state to one of the States j + 19 through j + 22, is considered to be zero. States j + 19 through j + 22 describe the levels of damage that could be caused by a 'near miss' of the EFOGM. It is also assumed that a 'near miss' can not cause catastrophic target destruction (State j + 18).

- State j + 17 - Target Not Destroyed. State j + 17 indicates that though the EFOGM impacted on the target, the target was not destroyed. State j + 17 may transition to any one of the States j + 19 through j + 22 that describe the varying levels of damage caused by the missile's impact. There is no transition time between these states since the time between impact and a specific level of damage occurring is considered to be zero.

5. Battle Damage and Damage Assessment

States j + 18 through j + 22 identify the level of damage, including destruction, caused by the EFOGM on the target, while States j + 23 and j + 24 describe the battle damage assessment (BDA) made by the FO on the target:

- State j + 18 - Target Destroyed. State j + 18 is accessible only from State j + 15 (EFOGM Target Hit). It can transition to one of the BDA states, j + 23 (Re-shoot Mission), or j + 24 (Go to New Target). It is assumed that even though the target is catastrophically destroyed, the FO may make an incorrect BDA of the target and execute a repeat CFF on that target (a transition to State j + 23).

- States j + 19 through j + 22 - Damage Level States. These states describe the level of damage caused by the impact, or near miss of the EFOGM. There are five possible damage levels: Destroyed, Heavy, Moderate, Light, and None. The transition probabilities from either State j + 16, or j + 17 to these states will vary, since it is assumed, for example, that the probability of Heavy Damage (State j + 19) would be much higher from State j + 17 (Target Hit but Not Destroyed) than from State j + 16 (Target Missed). All damage level states transition to States j + 23 (Re-shoot Target) or j + 24 (Go to New Target).

- State j + 23 (Re-shoot Target). In this state, the FO has determined that the level of damage is insufficient enough to warrant a repeat of the fire mission.

The transition time from the damage states ($j + 16$ and $j + 19$ through $j + 22$) to this state represents the time needed by the FO to asses target damage and choose a course of action. Should a transition to this state occur, the only transition out is to State $j + 1$ (Transmit CFF) with probability of 1.0.

- State $j + 24$ (Go to New Target). In this state, the FO has determined the damage level is sufficient not to re-fire the target. The FO then begins searching for new targets (State 1). The transition time to this state is defined as the time needed by the FO to asses target damage and choose a course of action.

C. USE OF THE STATE SPACE DIAGRAM

As mentioned, the state space diagram is used to model a portion of the Extended Close Battlefield. The issue then becomes how to simulate this state space to return values of interest; specifically, the times required to process CFFs and prosecute enemy targets. The general layout of the state space lends itself for use in a simulation model that can replicate events on the battlefield and the times involved with those events. The following chapter will discuss the nature of that model, and the methods used for extracting desired information from the state space depiction.

III. MODEL DESCRIPTION

A. GENERAL DESCRIPTION

The simulation model used for this thesis was written in PASCAL. It uses a uniform probability random number generator to replicate a Monte Carlo draw which is used to determine along which arc the state space simulation will advance. A description of the random number generator is contained in the next section. Monte Carlo comparisons are based upon user defined transition probabilities (P_{ij}'s). Additionally, normal and lognormal probability distribution random number generators are used to determine the transition times of several states within the simulation. For the purposes of this thesis, certain transition probabilities and times are based on the author's professional judgment. A complete listing of transition probabilities and their source is located in Appendix E. However, the majority of the transition times are based upon previous studies that define specific actions and functions of the command and control process as time distributions [Ref. 2, p. 2-14]. PASCAL was chosen as the simulation language due to its ease of use, and because it does not require a particular operating system, other than DOS, to function. This ensures its execution on stand alone personal computers present in the majority of U.S. Army analytic agencies today.

Output from this simulation will allow the user to collect the number of times certain states were "visited" and the times from target detection to target prosecution and missile interaction. With data from a large number of simulation runs of both the digitized and non-digitized C^3 systems, operating range values for the two systems can be obtained. Summaries of these data can then provide possible input parameters for the EFOGM system in other simulation models, or can be used independently to study the differences in performance of the digitized versus the non-digitized system altering various input parameters.

B. RANDOM NUMBER GENERATOR

The computer code shown in Appendix C is the method used within the simulation model to generate random numbers from the uniform distribution on the interval [0,1] (noted as U(0,1)). The importance of the U(0,1) generator is that the random variates from other probability distributions (normal, lognormal, beta) can be generated by transforming a U(0,1) variate in a manner determined by the desired distribution [Ref. 7, p. 421]. The method used to generate the normal and lognormal variates is the <u>Inverse Transform</u> technique. An example from Law and Kelton provides a simple explanation of the technique:

> Let X have the exponential distribution with mean β . . . The distribution function is:
>
> $$F(x) = \begin{cases} 1 - e^{-x/\beta} & \mathit{if}\ x \geq 0, \\ 0 & \mathit{otherwise} \end{cases}$$
>
> so to find F^{-1}, we set $u = F(x)$ and solve for x to obtain:
>
> $$F^{-1}(u) = -\beta \ln (1 - u)$$
>
> Thus, to generate the desired random variate we first generate a $U \sim$U(0,1) and then let $X = -\beta \ln U$. [It is possible in this case to use U instead of $1 - U$, since $1 - U$ and U have the same U(0,1) distribution . . .] [Ref. 7, pg. 466]

Transition time values from the normal and lognormal distributions were generated, in this manner, for use in the simulation. To ensure that the random number generators were functioning properly, a small test program was written to generate 1000 random variates from the normal distribution on the interval [0.25, 0.2778] and from the lognormal distribution on the interval [0.41667, 0.0611]. These two values are provided in the BEWSS model as the random times to transmit a voice radio message and FSO processing time (in minutes), respectively. Shown in Appendix D are graphical and analytical distribution fits for each sample of 1000 variates. These were produced by the statistical program *A Graphical Statistical System* (*AGSS*). As shown in the Appendix D, the samples follow their respective distributions very closely, and verify the validity of the random number generators.

C. SIMULATED FLOW OF THE BATTLE

1. Main Program

The main program is a simple loop that executes a user defined number of replications of either the digitized, or non-digitized simulation model. Within this loop, a "master clock" is initialized that tracks current "battle time" throughout the program. A queue of records stored as a linked list (an event queue), called the **Calendar**, is created which stores **Events** to be executed, sorted by execution **Time.** Parameters such as which observer is searching (**Obsvr**), the target number acquired and engaged (**TgtNumb**), the **Missile** engaging a target, the **Launcher** from which the missile was fired, and a pointer to the next record (**Next**), are also stored within each record of the **Calendar**. For non-digitized replications, additional queues for CFFs that the FSO and LNO must process when they become free from processing previous CFFs, are initialized. The first event, "StartBattle" is placed on the Calendar to be executed at time 0.0 using *SCHEDULE*, which is a procedure outside the main program, but warrants explanation now.

The *SCHEDULE* procedure controls inputs to all queues. The first check *SCHEDULE* makes is to ensure the event time about to be scheduled is greater than, or equal to the current clock time. (Obviously, an event can not be scheduled to occur in the future if it has an execution time in the past.) If the event time meets the logic check, the event is placed on the queue. For example, scheduling the **Event** "CFF" (Call For Fire) requires values for the parameters **Observer** and **Target** (which are both integer values from one to the maximum number of FOs, or maximum number of targets, respectively). Because the **Missile** and **Launcher** parameters are not needed in the event "CFF", they receive integer values of zero (0). The parameter **EventTime** is a real value representing battle time <u>in minutes.</u> For the **Calendar, FSOList**, and **LNOList**, *SCHEDULE* places the values for the parameters listed above on the queue in a time sorted manner. The model includes calls to *SCHEDULE* when it determines an event should occur.

Finally, the main program calls either MASTERTIMER or MASTERTIMER2. MASTERTIMER is the subprogram for a non-digitized replication, while MASTERTIMER2 replicates the digitized C^3 system. These two sub-programs remove and schedule items from and to **Calendar**, **FSOList** and **LNOList**, keep track of the simulation clock, and execute the simulation. Each has several subroutines. All subroutines, minus those that replicate the digitized, or non-digitized form of processing, are similar for both sub-programs. Discussion of these subroutines will cover the common initial subroutines, break out the specifics for the digitized and non-digitized cases, and then discuss the final common subroutines. For simplicity purposes, future references to subroutines or procedures that are peculiar to either MASTERTIMER or MASTERTIMER2 will be noted as (**ND**: non-digitized) and (**D**: digitized), respectively. Additionally, some procedures will use probabilistic time distributions from which various processing and wait times for the simulation are drawn. These times are taken from the CSC technical report [Ref. 2], and are summarized in Appendix E.

2. Initial Common Subroutines

As stated, MASTERTIMER and MASTERTIMER2 control program execution. While the **Calendar** is not empty, they remove the parameters from the first record in the queue using the procedure "DeQueue". They then compare the event name taken off the **Calendar** to a list of indexed sub-routine event names. Once a match is found, the sub-program takes the index number for that event name and searches its indexed subroutines until a match is found between the index number and the indexed sub-routine. It then executes the events in the matching indexed sub-routine at the time drawn from the **Calendar**. The specifics of the initial common subroutines will now be discussed.

a. *"StartBattle"*

This sub-routine initializes any global variables to their beginning of battle values. For the computer model used in this thesis, the user defines these starting parameters by altering input parameters located in a text data file (example shown in Appendix F). "StartBattle" reads in the user defined parameters from the data text file, and as it loops over every combat entity, it is initialized to its beginning battle value. It also assigns transition probabilities, and inputs the initial ranges from every high value target in the scenario to every FO and EFOGM launcher. In particular, it schedules the sub-routine "Initialize" for all FOs to start at battle time 0.0.

b. *"Initialize"*

This sub-routine corresponds to States One through Five in the state space diagram (see Figure 1). It samples a U(0,1) and compares the sample to indexed transition probabilities that were assigned in the "StartBattle" sub-routine, to determine if the FO is detected. If not detected, it schedules the sub-routine "Search". If detected, the sub-routine makes another U(0,1) draw to determine if the FO is destroyed. If not destroyed, it schedules a "Search" and returns control to MASTERTIMER or MASTERTIMER2. If destroyed, it decrements the number of remaining FOs, updates the status of that particular FO to "Destroyed" and returns control to MASTERTIMER or MASTERTIMER2.

c. *"Search"*

"Search" corresponds to States 6 through *j* in the state space model. For the searching FO, it loops over <u>all</u> <u>possible</u> targets. If the damage level to the target is not "Destroyed", it draws a U(0,1) and checks the current range between the FO and that target. If the U(0,1) draw results in the target being in the FO's field of view (FOV) and the range to the target is within the maximum range of the FO, but not behind the FO (at a negative range), and the FO has not previously transmitted a CFF for this particular target, a time to acquire the target is determined using the DYNTACS detection rate equation [Ref. 4, pp. 77-79]. (See Appendix G for a discussion of the DYNTACS equation and related detection algorithms.) If that acquisition time is the smallest over all acquired targets for that FO, it is stored, along with the corresponding target number. If not, it loops to another target. This continues until all targets are sampled. Once the loop over all targets is complete, the minimum acquisition time for that FO over all targets is compared to the maximum time any FO can search without being re-initialized. This check prevents an FO from searching for long periods of time without running the risk of re-detection. If the minimum acquisition time is less than the maximum cycle time, a "CFF" (Call for Fire) is scheduled at the clock time plus the calculated minimum acquisition time. If not, the FO is re-initialized at the clock time plus the maximum cycle length time, and control returns to MASTERTIMER or MASTERTIMER2.

d. "CFF"

This sub-routine covers states $j+1$ and $j+2$. A U(0,1) is drawn to determine the success of the attempted contact between the FO and the DRB HQs (ND) or AFATDS (D). If successful, a "BdeProcess" (ND) or "AFATDS" (D) is scheduled at the input clock value plus a random time value from the normal distribution, and control returns to MASTERTIMER or MASTERTIMER2. If a U(0,1) draw indicates a failure to successfully contact the DRB HQ/AFATDS, additional attempts are made using different U(0,1) draws. This process continues until the Monte Carlo draw indicates successful contact is made, or until a user defined amount of time has past. If that point is reached, the FO quits trying to make contact and an "Initialize" is scheduled at the input clock value plus the user defined time, and control then returns to MASTERTIMER or MASTERTIMER2.

3. Non-Digitized Processing Common Subroutines

a. "BdeProcess"

"BdeProcess" is one component of State $j + 3$ (see Figure 2). Here, a random lognormal value is drawn to represent the time necessary for an RTO to process (record) the FO's CFF. A truncated random normal value is then determined to represent the time spent checking the status of the FSO. These two events constitute the brigade processing time. The event "FSOProcess" is then scheduled on the **Calendar** at the clock value plus the brigade processing time. If the FSO can process no more CFFs (i.e., there are no missiles left to shoot), the message is not passed to the FSO. Control then returns to MASTERTIMER.

b. "FSOProcess" and "FSOFree"

Another component within State $j + 3$ is the "FSOProcess" sub-routine. If the FSO is busy when the event is taken off the queue (checked with a boolean), the mission is queued on the **FSOList**. If the FSO is not busy when the CFF arrives, two random lognormal samples drawn to replicate the times needed for the FSO to process the CFF and then deliver it to the EFOGM LNO cell. If the total process time for the fire mission, from the FO's CFF to hand-off to the LNO, is less than a user defined value, the mission is delivered to the LNO by scheduling "LNOProcess". Should the total process time exceed the user defined amount, the CFF is not processed any further. It is assumed that because of the delay in processing that the additional time required to process the mission and then fly the missile to the target will seriously degrade the possibility that the EFOGM will acquire the proper target within the engagement area. At the same time the "LNOProcess" is scheduled, an "FSOFree" is scheduled to occur. The "FSOFree" procedure changes the boolean value for the FSO and checks the FSO queue for any missions. If any missions are on the queue, they are taken off and an "FSOProcess" is scheduled at the current clock value. If the **FSOList** is empty, the FSO waits for his next CFF. Control then returns to MASTERTIMER.

c. *"LNOProcess" and "LNOFree"*

The "LNOProcess" sub-routine first checks to ensure that the LNO is not busy processing a previous CFF. If he is, the new mission is placed on the **LNOList** and control returns to MASTERTIMER. If the LNO is not busy and the total number of CFF processed is less than the maximum number of missiles, two random lognormal samples are drawn representing the EFOGM LNO processing time and the time needed to transmit the firing order over the radio to the battery. A "LNOFree" is then scheduled at the sum of the two samples.

Similar to the "FSOFree", the "LNOFree" procedure changes the boolean value for the LNO and checks the LNO queue for any missions. If any missions are on the queue, they are taken off and an "LNOProcess" is scheduled at the current clock value. If the **LNOList** is empty, the LNO waits for his next CFF

A Monte Carlo draw is then conducted to confirm if the EFOGM battery can receive the CFF from the EFOGM LNO by radio. If contact can be made, a "BtryProcess" is then scheduled at the clock time plus the sum of the two lognormal samples, and control returns to MASTERTIMER. Should the Monte Carlo draw indicate that radio contact is not initially made, U(0,1) draws are made until the value of the draw is equal to, or exceeds the value needed to transition into State $j + 3e$ (CFF Received by EFOGM Battery). Each retransmission adds a user defined amount of time to the total processing time. Once contact is established, a "BtryProcess" is scheduled at the sum of the two lognormal samples and the extra time needed to establish radio contact. Control then returns to MASTERTIMER.

d. *"BtryProcess"*

The "BtryProcess" sub-routine compiles the total time for the battery platoon leader to predict an intercept location for the target, process and issue the fire command, and for the EFOGM gunner to apply the data to the launcher. These four times are represented by four distinct lognormal random number draws. By calling the procedure "GetLaunchTime", the launch time for the mission is determined. If the target is currently within the maximum range of the missile, a "Launch" is scheduled immediately. If the range to the target, after the time incurred during a flight time to maximum missile range, is greater than the maximum range of the missile, the procedure calculates the time at which the missile should be launched, taking into account the flight time of the missile to maximum range, and the speed of the target vehicle to the engagement area. The event "Launch" is then scheduled for a time equal to the current clock value plus the time to launch. Control then returns to MASTERTIMER.

4. Common Digitized Processing Subroutines

a. "AFATDS"

"AFATDS" represents the processing of a CFF by the AFATDS computer. First, the procedure "CFFTimes" calculates the amount of time (in terms of the number of transmission attempts needed to establish radio contact) it takes the AFATDS to establish radio communication with the BDE, PL and battery. It does this by sampling a U(0,1) and comparing it to the user defined probability of establishing first time contact. If the Monte Carlo draw is successful, "CFFTimes" returns the integer value "1". If unsuccessful, U(0,1) draws are repeated until the draw is greater than the user defined probability of not establishing contact on succeeding tries. Each successive try increments a counter until contact is established. "CFFTimes" then returns the integer value of the number of attempts needed to establish radio contact. "AFATDS" then checks to ensure that a CFF has not been previously processed for the particular target and that the total number of CFFs processed is less than the maximum number of EFOGM. If these conditions are not met, the sub-routine does not schedule the target for further processing. If the conditions are met, the total number of CFF is incremented, and the target is registered as being processed. The value of "CFFTimes" is sampled each time for the brigade, platoon leader and battery. If the "CFFTimes" value is "1", a "BdeProcess", "PLProcess" or "GunProcess" is scheduled at the clock value plus the time required for the AFATDS to process the CFF, and then send it to a subordinate unit. Should the "CFFTimes" not equal "1", it schedules a "BdeProcess", "PLProcess" or "GunProcess" at the clock value plus the sum of AFATDS processing time, transmission time, and the "CFFTimes" value multiplied by a user defined amount of time required for retransmission attempts.

b. *"BdeProcess"*

"BDEProcess" first samples the number of times needed to establish radio contact with the PL using the procedure "CFFTimes", discussed above. It then checks to ensure the acquired target is "High Priority". If so, and the "CFFTimes" value is "1", it schedules the subroutines "BDE1" and "PLProcess" at the clock value plus the time required for BDE to confirm the mission and transmit the confirmation to the PL. If the "CFFTimes" is not greater than "1", the two subroutines are scheduled at the time just mentioned, plus the extra time required for retransmissions, as discussed in the section above. Should the target not be "High Priority", "BDEProcess" schedules a "BDE2" and "PLProcess" using the same logic mentioned for "BDE1" and PLProcess".

c. *"PLProcess"*

Logically complicated, "PLProcess" accounts for the PL receiving data not only from AFATDS, but also mission confirmations from BDE. The PL normally receives initial mission data from AFATDS. However, if communications between AFATDS and the PL break down, it is assumed that the PL will accept mission information from the first unit, AFATDS or BDE, who sends him the new data. Therefore, there are three possibilities that could occur within "PLProcess". The first, and most likely possibility is that AFATDS passes the mission data to both BDE and PL simultaneously. "AFATDS" replicates this by scheduling "BDEProcess" and "PLProcess" to occur at the same clock value. Once the BDE and PL have received the mission data, "BDEProcess" schedules a second "PLProcess" to occur at a later time, while the PL waits for BDE to confirm the mission. At the beginning of the second pass through "PLProcess" (scheduled by "BDEProcess"), BDE has now confirmed the mission, and passes this confirmation to the PL. "PLProcess" simulates the PL confirming the mission, and then schedules a "PL1" (if BDE passes a "Hold-Fire") or "PL2" (if BDE passes a "Fire"), and a "GunProcess". These subroutines are scheduled to occur at the clock value plus the time needed by the PL to contact the battery with mission confirmation and firing status. (Again, taking into account the "CFFTimes" number discussed previously.)

The second possibility is that the PL does not receive the CFF data from AFATDS until after BDE passes mission information to the PL. "AFATDS" simulates this by scheduling a "PLProcess" at a time later than it schedules a "BDEProcess". As "BDEProcess" is executed, it schedules a "PLProcess" at a time that is still less than the first "PLProcess scheduled by "AFATDS" . Should this occur, BDE has now initiated the CFF to the PL, and the PL will pass the mission confirmation and firing status to the battery, as mentioned in the previous paragraph. Finally, when the AFATDS mission arrives to the PL (simulated when the "PLProcess" scheduled by "AFATDS" is taken off the queue), the data are disregarded since it has already been forwarded to the battery.

The final possibility occurs if the BDE does not receive the AFATDS data until well after the PL does. This case is no different, in a computer logic sense, than the first. The PL receives the data from AFATDS, and then must wait for BDE to confirm the mission, so he can pass the mission confirmation to the battery.

d. "GunProcess"

"GunProcess" is also logically complicated, and consists of two possible cases, with two sub-cases within the first case. The first possibility is that the AFATDS mission data arrive at the PL and battery at the same time. "AFATDS" simulates this by scheduling the subroutines "PLProcess" and "GunProcess" at same clock value. Battery processing of the data is replicated in "GunProcess" by sampling a series of three lognormal time distributions, and changing the target number indexed boolean variable, **ProcessingData**, to “True”. There are two possible sub-cases for the first possibility.

In sub-case one, the PL confirmation *before* the battery completes initial processing of the mission data, “GunProcess” samples the first two lognormal time distributions, and schedules a “Gun1” at the clock value plus the sum of those initial times. (“PL1” or “PL2”, which “PLProcess” scheduled, changes the value of the target number indexed boolean, **PLConfirm,** to “True”.) When the “Gun1” is taken off the event queue, it checks to see if **PLConfirm** is “True”, which it will be. Since the PL has confirmed the mission, “Gun1” schedules a “Launch”, taking into account the current ranges to the target and missile flight times (see “BtryProcess” discussion of “GetLaunchTime” procedure above).

The second sub-case occurs if the PL confirmation arrives *after* the battery has finished initial processing of the mission data. (“PLProcess” schedules a “PL1” or a “PL2” and a “GunProcess” at a time after the time “GunProcess” and “Gun1” finishes initial data processing.) In this sub-case, when “Gun1” checks the boolean **PLConfirm** it is “False”. (“PL1” or “PL2” has still not executed to change the boolean value.) Therefore, the sub-routine “GUN1” must wait for the PL confirmation to arrive, turns the value of a target number indexed boolean **DataProcessed** to “True”, and does not schedule a launch. When the “GunProcess” scheduled by “PLProcess” is executed, **DataProcessed** is “True”, and a launch is schooled through the procedure “GetLaunchTime”.

The second possible case occurs if the battery does not receive the AFATDS data before the PL confirmation arrives. In this case, the PL transfers the data to the battery and the battery begins immediate processing of the mission. In the simulation, this means that the “GunProcess” scheduled by “AFATDS” occurs at a time *after* the “GunProcess” scheduled by “PLProcess”. As the “GunsProcess” scheduled by “PLProcess” is executed, the value of **ProcessingData** is “False”. This now becomes a PL initiated CFF, and the sub-routine changes the value of **ProcessingData** and

PLInitiated to "True", collects a total sample of the three lognormal processing times, and uses "GetLaunchTime" to schedule a launch. When the "AFATDS" scheduled "GunProcessed" is eventually executed, the booleans **ProcessingData** and **PLInitiated** are both "True", so no mission is processed.

e. "BDE1"

"BDE1" is scheduled by "BDEProcess" and represents the time at which the BDE establishes contact with the PL and passes the mission confirmation and firing status "Fire" to the PL. The observer and target number indexed boolean variables **BDEHF** and **BDEConfirm** are changed to "False" and "True", respectively, indicating that BDE wants the mission to be fired.

f. "BDE2"

"BDE2" is scheduled by "BDEProcess" and represents the time at which the BDE establishes contact with the PL and passes the mission confirmation and firing status "Hold Fire" to the PL. The observer and target number indexed boolean variables **BDEHF** and **BDEConfirm** are both changed to "True", indicating that BDE does not want the mission to be fired.

g. "PL1"

"PL1" is scheduled by "PLProcess" and represents the time when the PL establishes contact with the battery and passes the mission confirmation and firing status to the battery. The observer and target number indexed boolean variables **PLConfirm** and **PLHF** are both changed to "True", indicating that the PL has confirmed the mission and is passing a "Hold-Fire" to the battery for the mission.

h. "PL2"

"PL2" is scheduled by "PLProcess" and represents the time when the PL establishes contact with the battery and passes the mission confirmation and firing status to the battery. The observer and target number indexed boolean variables **PLConfirm** and **PLHF** are changed to "True" and "False", respectively, indicating that the PL has confirmed the mission and is passing a "Fire" to the battery for the mission.

I. "GUN1"

"GUN1" is scheduled by "GunProcess" and represents the time when the battery has completed initial processing of the mission data from AFATDS. First, the observer and target number indexed boolean variable **DataProcessed** is changed to "True". The value of the variable **PLConfirm** is then checked. If **PLConfirm** is "True" and **PLHF** is "False", "GetLaunchTime" is called to schedule the launch of a missile for the target. If **PLConfirm** is "False", nothing further is scheduled, and control returns to MASTERTIMER2.

5. Final Common Subroutines

a. "Launch"

The "Launch" sub-routine replicates the "pulling of the trigger" by the gunner (State $j + 4$). A U(0,1) draw is made to determine if the missile is lost at launch (State $j + 5$), misfires and the gunner re-fires (State $j + 6$), or if there is a successful launch (State $j + 8$). The path determined by the Monte Carlo draw determines which sub-routine is scheduled, and then returns control to MASTERTIMER.

b. "MisFire"

This sub-routine replicates the events in State $j + 6$. As discussed in the previous chapter, there are four possible transitions from this state. A single U(0,1) sample is drawn, which determines the state to which transition is made. If the Monte Carlo draw indicates a transition to State $j + 5$ (EFOGM Lost), the number of remaining EFOGMs is decremented and control returns to MASTERTIMER or MASTERTIMER2. If the transition indicates another misfire, the "MisFire" sub-routine is scheduled again after a user defined delay and control returns to MASTERTIMER or MASTERTIMER2. A transition to State $j + 7$ (Dud Missile/Select New Missile|Reshoot) causes the "DudRefire" sub-routine to be scheduled after a user defined time delay, the number of remaining EFOGMs is decremented, and returns control to MASTERTIMER. The last option leads to the scheduling of "Flight" (State $j + 8$, Successful Launch) with no delay in time, and returns control to MASTERTIMER or MASTERTIMER2.

c. *"DudRefire"*

This sub-routine represents State $j + 7$ (DudRefire). It draws a U(0,1) random number to determine the succeeding state. Since State $j + 7$ can transition to the same states as discussed in the "Launch" sub-routine, "DudRefire" executes the same algorithms, except with different user defined state transition probabilities. It then decrements the number of available EFOGMs, and returns control to MASTERTIMER or MASTERTIMER2.

d. *"Flight"*

This sub-routine considers all possible occurrences during the EFOGM flight after a successful launch (State $j + 8$). It calculates the flight time of the missile to the target and range of the launcher to the target using the functions *TIMEOFFLT* and *RANGE2*. (*TIMEOFFLT* is a procedure that calculates the time the missile will need to fly to the target, taking into account the forward velocity of the target. *RANGE2* is a procedure that calculates the current range from launcher to target based on initial range and elapsed time and target velocity.) A U(0,1) draw is first made to determine if the missile is detected while in flight. If comparison with a user defined probability of detection results in the missile not being detected (State $j + 10$), another U(0,1) is drawn to determine if the missile becomes lost while in flight (State $j + 13$). If the missile is not lost in flight, transition to State $j + 14$ (EFOGM Target Acquisition/Lock On) is simulated, and the sub-routine "Impact" is scheduled to occur at a time equal to the current clock value plus the time of flight. Control then returns to MASTERTIMER or

MASTERTIMER2. If the missile is lost in flight, the event is considered to have occurred at a time value equal to the clock value plus one half of the time of flight value.

If the missile is detected in flight, another U(0,1) draw is made to determine if the enemy destroys the missile in flight (State $j + 11$). If the missile is destroyed, the sub-routine ends and control returns to MASTERTIMER or MASTERTIMER2 with no further events scheduled. If the Monte Carlo draw indicates the missile is not destroyed in flight after enemy detection (State $j + 12$), a final U(0,1) draw is made to determine if transition is made to State $j + 13$ or $j + 14$. Results of these transitions were discussed in the previous paragraph.

e. "Impact"

The "Impact" sub-routine covers States $j + 15$ and $j + 18$. A U(0,1) draw determines if the missile impacts on the target (State $j + 15$) or is a near miss (State $j + 18$). If the Monte Carlo draw indicates an impact on the target, an additional U(0,1) draw is made to determine if the target was destroyed (State $j + 16$), or only damaged by the resulting explosion (State $j + 17$). If the second draw indicates the target was only damaged, a third U(0,1) draw is compared to user specified probabilities that determine the probability of certain damage levels (States $j + 19$ through $j + 22$), given impact on the target. This third draw determines to which damage level state transition is made. Once in the damage level state, the damage level to the target is assigned to an array. Possible damage levels are "Destroyed", "Heavy", "Moderate", "Light", and "None" (indicating a dud warhead round, or missile impact so far away from the target that no collateral damage was caused by the warhead explosion). For simulation purposes, damage levels are assumed to be consistent across all enemy vehicle types. (These can be readily changed to support user specific analyses.) Once the damage level has been changed, the sub-routine "BDA" is scheduled and control returns to MASTERTIMER or MASTERTIMER2.

If the missile misses the target (State $j + 18$), a U(0,1) draw determines the level of damage achieved from a warhead detonation near the target, and determines the corresponding transition state. Again, once the damage level annotated, the sub-routine "BDA" is scheduled, and control returns to MASTERTIMER or MASTERTIMER2.

f. "BDA"

It is assumed that once impact occurs, the FO immediately begins the BDA process. The final sub-routine, "BDA", represents the FO's determination of the level of damage caused by the EFOGM missile to a target. The sub-routine searches for a match between the target's damage level and the damage levels in the sub-routine. Once a match is made, a U(0,1) draw determines if the FO decides to repeat the fire mission on the target. The comparison is based upon user defined probabilities of repeating a CFF, given the specific damage level to the target. If the U(0,1) draw indicates that a repeat of the fire mission is not attempted, the sub-routine ends and control returns to the MASTERTIMER or MASTERTIMER2. However, if the U(0,1) indicates that a repeat CFF is made, "CFF" is scheduled to occur at the current clock time plus a user defined amount of time needed by the FO to asses battle damage, and control returns to MASTERTIMER or MASTERTIMER2.

D. REPLICATION COMPLETION

The program will continue to schedule events until the battle clock reaches 200 minutes. At this time, all enemy vehicles moving at the constant rate of 5.55 meters per second would be "on top of" the friendly battle position. When this occurs, the MASTERTIMER or MASTERTIMER2 procedure will continue to remove the events "Search" and "CFF", but since either no missiles or FOs are remaining, no further processing can occur, and no processing events are added to the **Calendar**. When the time limit is reached, program control returns to the main routine that begins to write the output data for the replication to a text file.

E. DATA COLLECTION

Within each sub-routine, counters are established to determine the number of "visits" to that specific sub-routine. The counter variable **VisitTimes[State#,Obsvr,Tgt]** counts the number of times a CFF for a specific FO and target is processed in various routines in the model. These routines represent various states in the state space diagram, so the number of times a FO acquires a specific target (done in the "Search" sub-routine) can be documented. Additionally, time recorders are employed to capture the time each event occurs. The variable **OutData[VisitTimes,Obsvr,Tgt,State#]** records the time at which a numbered CFF for a specific FO and target "visits" a specific routine in the program. Because of repeat fire missions that may occur, the same FO and target may visit the "CFF" procedure more than once. Collection of these data allows comparison of the amounts of time required to traverse from state *i* to state *j*. These data are written to a text file that can be loaded into a statistical analysis package for use in determining distributions and data tendencies. The following chapters discuss the plan for data collection and its analysis.

IV. ANALYSIS

A. GENERAL

The purpose of this chapter is to demonstrate the performance of the simulation model within specified parameters, and to demonstrate its sensitivity to any changes in the input parameters. The base case for the model's execution calls for 69 high value targets to be engaged by 48 EFOGM. This scenario is based upon the simulation depicted in HRS 33.5 that was mentioned in previous sections. The mean time and variance values used for producing probabilistic time values within the simulation model were taken from the Computer Science Corporation (CSC) Technical Report [Ref. 2, Figures 2-4/13] on C^3 time delays within the EFOGM CFF process. However, during the stress of combat and continuous operations, the mean times stated for performance of human tasks by CSC in their technical report were considered to be slightly optimistic, based on observations of human performance during continuous operations in combat and high intensity training environments, such as the National Training Center. Additionally, the processing time for the AFATDS computer [Ref. 2, p. 27a] to accept, logically process, and forward the numerous CFFs present on the modern battlefield is relatively small, considering the abilities of current micro-processors that are able to withstand the durability requirements of DOD hardware and the environmental extremes that may be met in combat operation areas. Accordingly, mean times for human tasks (i.e., CFF processing, intercept prediction plotting, issuing firing orders) for both the digitized and non-digitized cases, and the mean processing time for the AFATDS computer in the digitized case, were increased by 25% to reflect the perceived time underestimation. Simulation runs executed under these new mean time values constituted the base case + 25% replications. Values for the variance for each adjusted mean were assumed to have remained the same. Replications were made for both the digitized and non-digitized scenarios using the two input time parameters. The following sections discuss the base case and the base case + 25% data collection and replication outcomes.

B. DATA COLLECTION

For each replication run, time events (measured in minutes) were recorded for use in data analysis. Time events in both the digitized and non-digitized cases were recorded for a specific target and observer. Similar events for the digitized and non-digitized replications include:

- Time of detection (T1).
- Time the battery completes CFF processing (T8).
- Time a missile was lost at launch (LAL), failed to fire or is a DUD round (T9).
- Time of a successful launch (T10).
- Time of impact (T11).

Events specific to the non-digitized replications include:

- Time the CFF arrived at the brigade HQs (N2).
- Time the CFF arrived at the FSO (N3).
- Time the FSO began processing the CFF (N4).
- Time the CFF arrived at the LNO (N5).
- Time the LNO began processing the CFF (N6).
- Time the battery began processing the CFF (N7).

Events specific to digitized replications include:

- Time the CFF arrived at the AFATDS for processing (D2).
- Time the CFF arrived at the BDE cell (D3) after being sent from AFATDS.
- Time the CFF arrived at the PL cell (D4) after being sent from AFATDS.
- Time the CFF arrived at the Battery (D5) after being sent from AFATDS.
- Time the PL receives mission confirmation from the BDE cell (D6).
- Time the battery receives mission confirmation from the PL (D7).

To compare/contrast the differences between the digitized and non-digitized systems, the total CFF processing time was needed. The total CFF processing time is simply the difference between the time the target was detected (T1) and the time the battery finishes processing the CFF (T8). The output matrices of event times organized by observer and target were then converted into spreadsheet format. (See Appendix N for an example of an output data file.) Simple column operations determined the time difference between T1 and T8 for each CFF that resulted in a missile launch. Twenty-five simulation replications produced 1200 values for total CFF processing time. Additionally, for the non-digitized case, the time a CFF spent "waiting" in the FSO or LNO queue was determined by finding the difference between event times N4 and N3 (FSO queue time) and event times N6 and N5 (LNO queue time). These columns of numbers were then used to create descriptive statistics and estimate probability distribution fittings for the processing times produced by replications of the simulation. An analysis of these times will now be discussed in detail.

C. NON-DIGITIZED REPLICATIONS

1. Base Case

Using 25 non-digitized replications of the simulation model, the descriptive statistics contained in Table 2 were obtained.

State 8 Time - State 1 Time = Processing Time	Non-Digitized Data
Mean	9.328
Standard Error	0.099
Median	8.855
Mode	7.225
Standard Deviation	3.457
Sample Variance	11.955
Kurtosis	0.663
Skewness	0.919
Range	18.248
Minimum	4.651
Maximum	22.899
Sum	11193.817
Count	1200
Largest(1)	22.899
Smallest(1)	4.651
Confidence Level(95.000%)	0.196

Table 2. Descriptive Statistics, Non-Digitized Replications, Base Case

The histogram shown in Figure 4 shows the shape of the data for the processing times of the non-digitized base case replications.

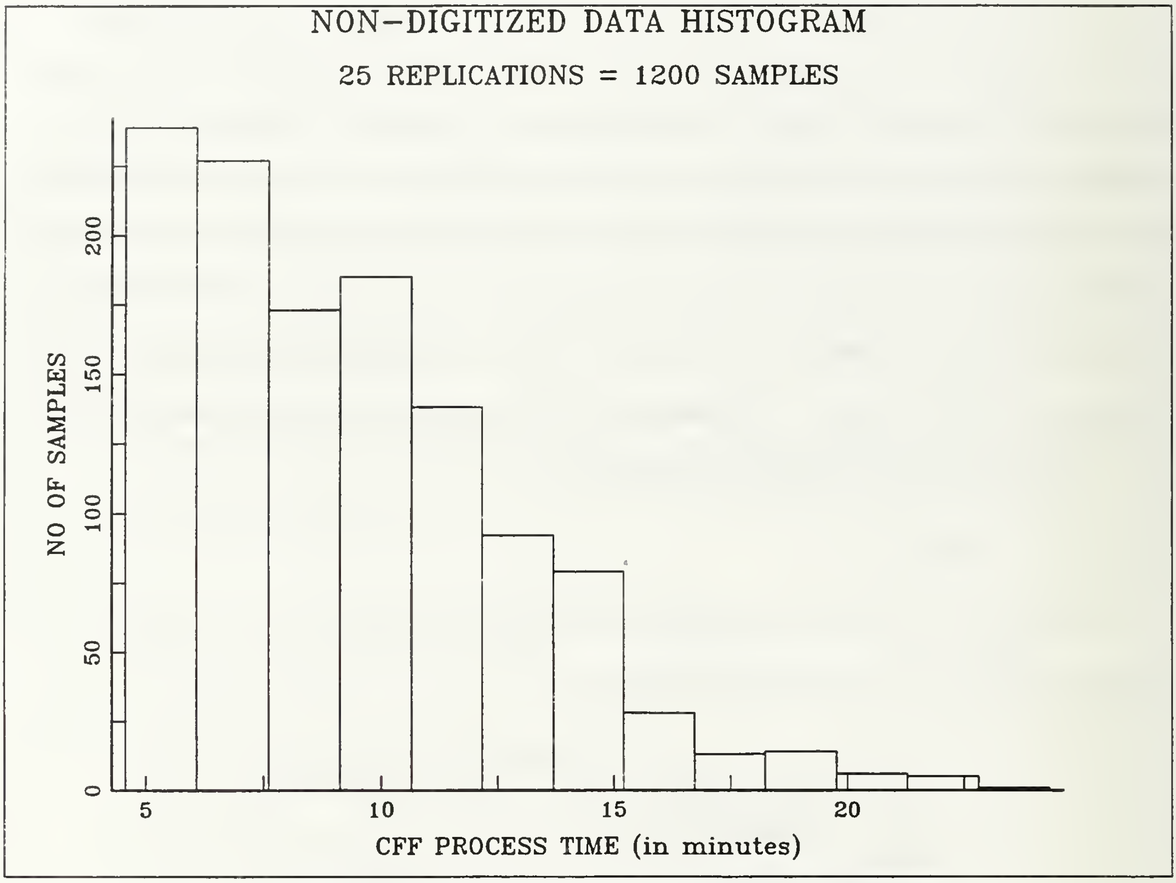

Figure 4. Histogram for Non-Digitized Data

Using the program *BestFit©*, the 1200 data points were analyzed and specific distributions ranked according to the chi-square, Kolmogorov-Smirnov and Anderson-Darling goodness-of-fit tests. This allowed the elimination of unlikely distributions from consideration. Choosing only the top three distributions for extensive analysis, the statistical package *AGSS* was used to specifically determine how well the data followed the chosen probability distributions recommended by *BestFit©*. The exploratory data analysis conducted by *AGSS* identified the data came nearest to matching the lognormal ($\mu = 2.168$, $\sigma = 0.3563$) or Gamma ($\alpha = 7.916$, $\beta = 1.79$) distributions. Graphical displays showing the density function, cumulative distribution function, cumulative hazard function, the probability plot and the analysis for the lognormal distribution fit are shown in Appendix J. While neither the Kolmogorov-Smirnov, Cramér-Von Mises, nor the Anderson-Darling goodness-of-fit tests demonstrate an exceptional fit, the graphical representations indicate the two distributions provide a relatively good match over the range of the data.

2. Base Case + 25%

Executing the simulation model using the non-digitized replication runs, and with time values adjusted as discussed in Section A, the data in Table 3 were obtained. Examining only the difference in the mean processing time for the base case and base case + 25% shows an increase in total processing time of over 8 minutes. The increase in the base case + 25% mean processing time is not a straight 25% increase over the base case mean processing time. The causes of this increase will be discussed later in the chapter.

State 8 Time - State 1 Time = Processing Time	Non-Digitized Data
Mean	17.107
Standard Error	0.201
Median	16.875
Mode	6.167
Standard Deviation	6.946
Sample Variance	48.251
Kurtosis	-0.938
Skewness	0.161
Range	29.889
Minimum	5.844
Maximum	35.733
Sum	20511.111
Count	1199
Largest(1)	35.733
Smallest(1)	5.844
Confidence Level(95.000%)	0.393

Table 3. Descriptive Statistics, Non-Digitized Replications, Base Case + 25%

The histogram shown in Figure 5 shows the shape of the data for the processing times of the non-digitized, base case + 25% replications.

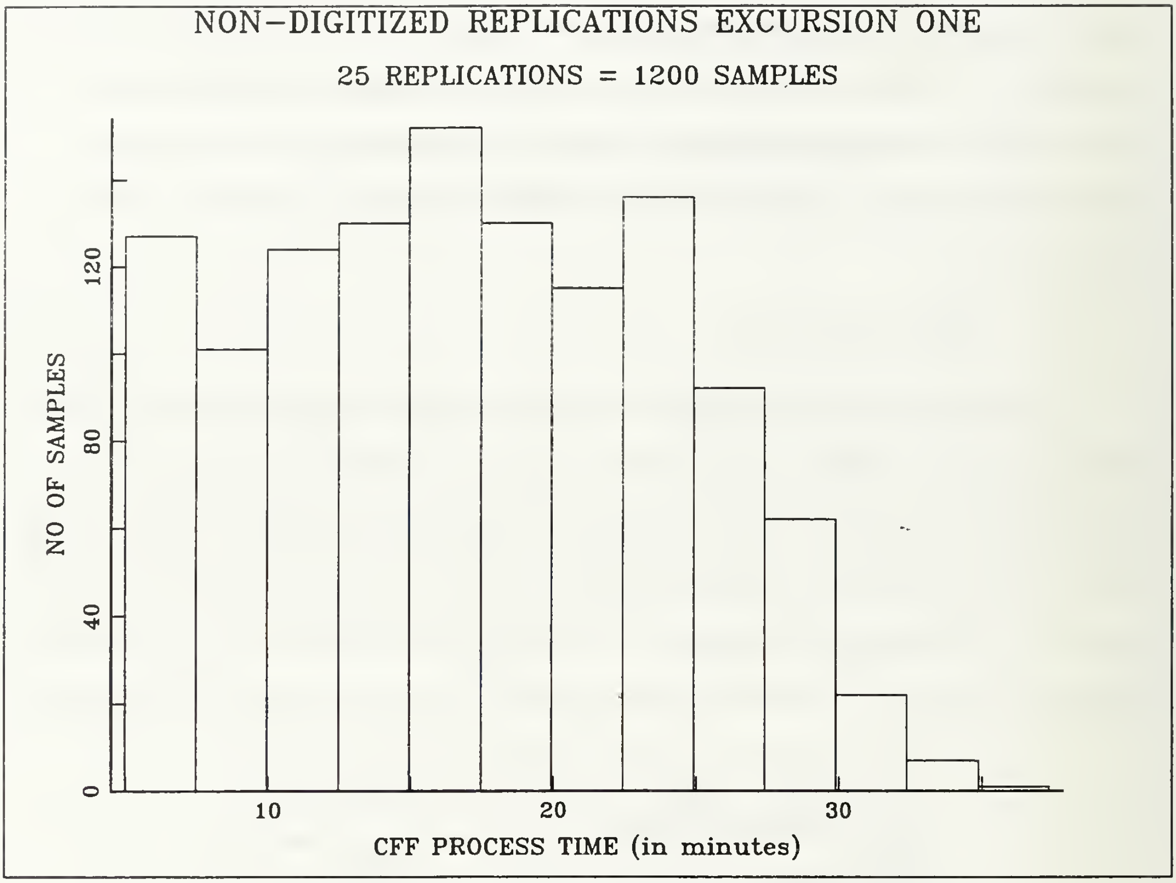

Figure 5. Histogram for Non-Digitized Data, Base Case + 25%

Using *BestFit*©, the empirical data was examined for a possible fit to probabilistic distributions. The two distributions chosen by *BestFit*© were examined by *AGSS* which showed the data followed the Weibull ($\alpha = 2.708$, $\beta = 19.292$) and Beta ($\alpha_1 = 2.729$, $\alpha_2 = 2.924$) distributions. *AGSS* showed no significance within the standard goodness-of-fit tests, and graphical analysis showed the empirical distribution of the data does not closely follow either distribution. (See Appendix K).

D. DIGITIZED REPLICATIONS

1. Base Case

Again, 25 simulation replications were executed to generate 1200 data points for the digitized base case version of the model. Shown in Table 4 are descriptive statistics for the processing time for those replications.

State 8 Time - State 1 Time = Processing Time	Digitized Data
Mean	1.456
Standard Error	0.004
Median	1.447
Mode	1.447
Standard Deviation	0.133
Sample Variance	0.018
Kurtosis	2.169
Skewness	0.829
Range	1.098
Minimum	1.12
Maximum	2.218
Sum	1747.67
Count	1200
Largest(1)	2.218
Smallest(1)	1.12
Confidence Level(95.000%)	0.008

Table 4. Descriptive Statistics, Digitized Replications, Base Case

Shown in Figure 6 is a histogram showing the general shape of the data for the digitized base case CFF processing time.

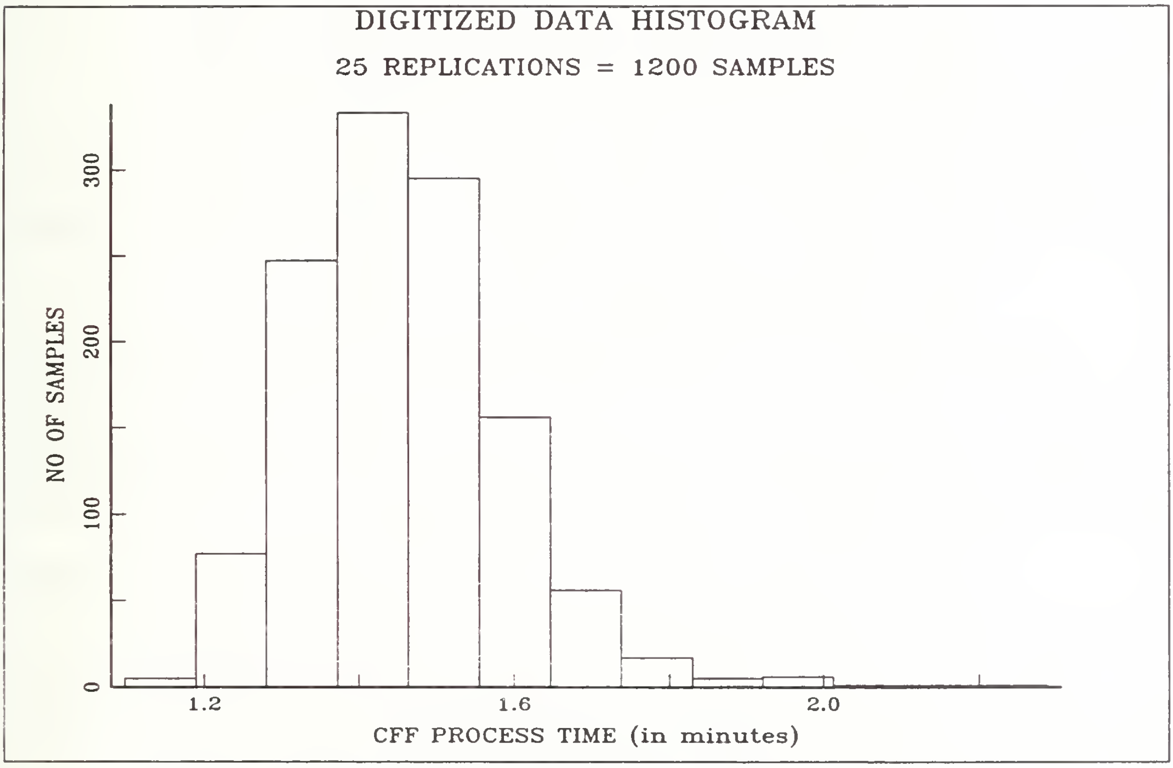

Figure 6. Histogram for Digitized Data, Base Case Replications

Using *BestFit©* and *AGSS* the empirical data was shown to fit the lognormal (μ = 1.456, σ = 0.0889) distribution at a very reasonable significance level for the Kolmogorov-Smirnov, Cramér-Von Mises and Anderson Darling goodness-of-fit tests. The graphical depiction and statistical analysis of data fit are shown in Appendix L.

2. Base Case + 25%

Similarly, 25 simulation replications were executed for the digitized, base case + 25% version of the model. Descriptive statistics for the processing time are contained in Table 5.

State 8 Time - State 1 Time = Processing Time	Digitized Data
Mean	1.748
Standard Error	0.0044
Median	1.743
Mode	1.739
Standard Deviation	0.138
Sample Variance	0.019
Kurtosis	1.630
Skewness	0.504
Range	1.284
Minimum	1.385
Maximum	2.669
Sum	2097.625
Count	1200
Largest(1)	2.669
Smallest(1)	1.385
Confidence Level(95.000%)	0.008

Table 5. Descriptive Statistics, Digitized Replications, Base Case + 25%

The empirical distribution of the 1200 processing time data values from these replications is shown in the histogram in Figure 7.

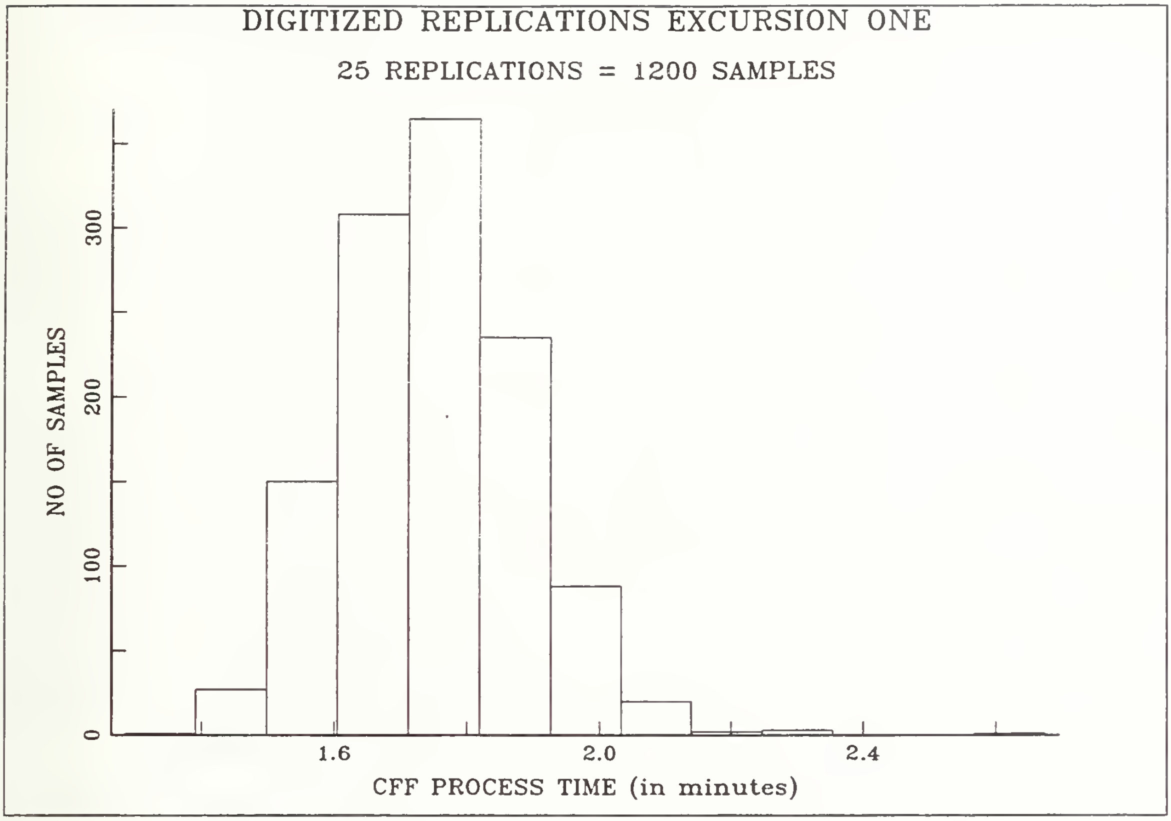

Figure 7. Histogram for Digitized Data, Base Case + 25%

Similar to the base case for the digitized replications, *BestFit©* showed a strong correlation with the lognormal distribution. *AGSS* confirmed this finding at a high significance level for all goodness-of-fit tests, and showed the data to fit the Lognormal (μ = 1.748, σ = 0.138) Distribution. Graphical and statistical descriptions of the distribution fitting are shown in Appendix M. Contrary to the increase in the mean processing time between the Base Case and Base Case + 25% cases in the Non-Digitized replications, the mean processing time in the Base + 25% case of the digitized replications is almost exactly 25% higher than the base case, indicating the increase in mean processing time to be purely a function of the increased mean values of the input parameters.

Another concern would be to check if the digitized system remained constant over the range of target availability. To test this premise, both digitized scenarios were executed with the standard 69 targets, and then with 35, or approximately half the number of original targets available. Unsurprisingly, the digitized processing times remained constant within the two cases over the range of targets available.

E. COMPARISON/ANALYSIS

As shown in the previous sections, there is a marked difference in the performance of the digitized and non-digitized C^3 system for the EFOGM. However, this performance is based on a fixed number of targets, moving at a constant march rate, and at predetermined intervals, arriving into the target area. To determine the sensitivity of the model to changes in the number of targets available to the EFOGM C^3 system, a series of replications were executed with decreasing numbers of targets available for prosecution. The decreasing numbers were accomplished by "thinning" the target array by five targets at a time. Targets were not all taken from the middle or rear of the target array, but evenly removed from the array of high value targets approaching the battle area. This has an effect similar to adjusting the arrival rate of the targets. The ultimate goal is to determine at what point, in the number of targets approaching the battlefield, does the FSO and LNO queue become overloaded enough to significantly reduce the efficiency of the processing system. The premise behind this goal is that the queue times in the non-digitized system heavily influence the total processing time for the system. However, if the number of presented targets is such that one target can be acquired and processed for prosecution *before* the next target becomes available, then the FSO and LNO queue are not a factor in the total time needed to prosecute the target. Through the process of "divide and conquer", the number of targets available was halved, then halved again, and so on until the mean times in the FSO and LNO queues became approximately zero. At this point, processing time can only be attributed to the amount of time required to process targets, and not a function of time waiting to be processed. Shown in Figure 8 is a composite graph depicting the increase in the mean base case processing time for non-digitized replications versus the mean base case processing time for digitized replications. The distribution of results for the non-digitized case are further represented by box plots.

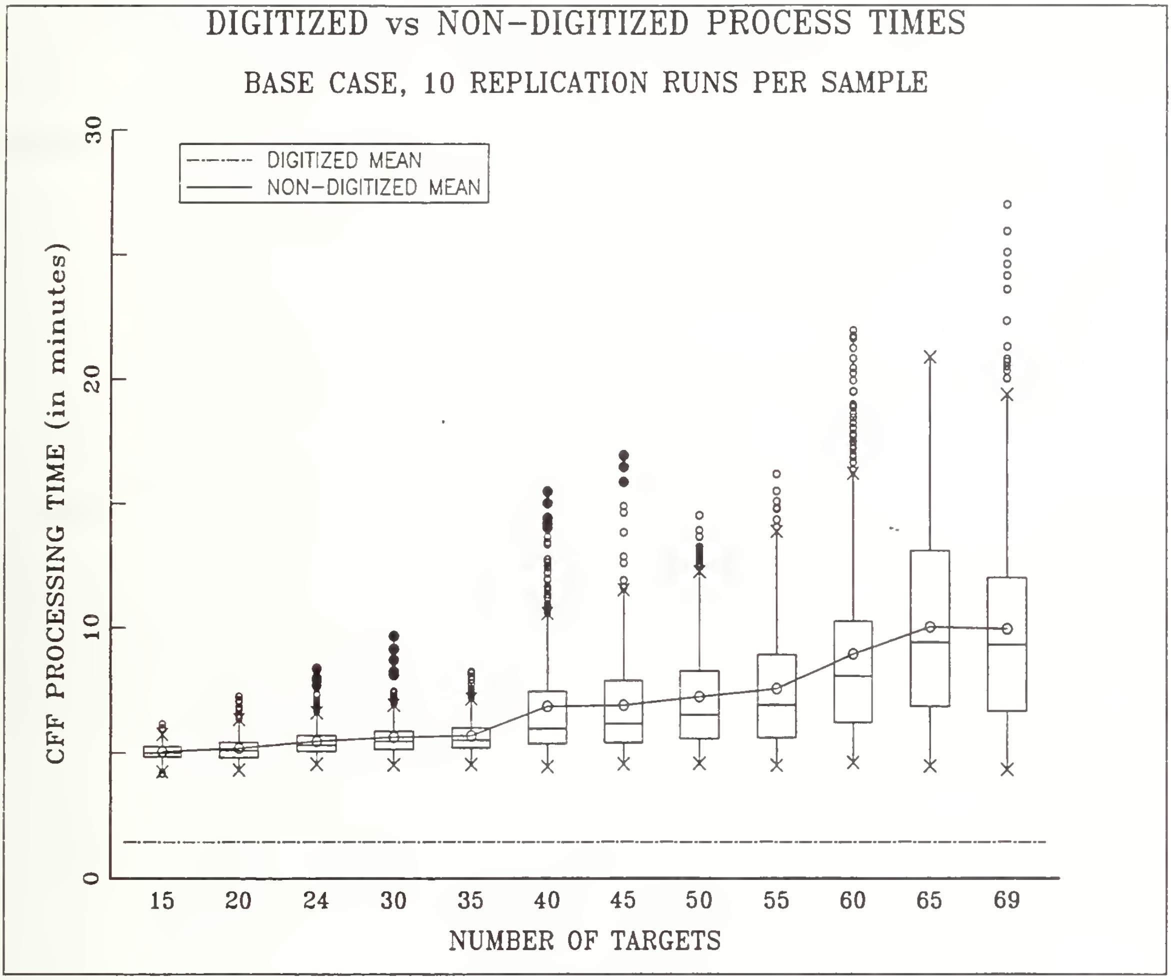

Figure 8. Composite Graph, Digitized/Non-Digitized Target Processing Times, Base Case

From about 15 to 35 targets, the increase in the mean and variance of the processing time for non-digitized replications remains relatively small, and the delta between digitized and non-digitized CFF process time remains almost constant. However, at 40 targets, the mean and variance for the corresponding target numbers begin to show a marked increase, while the processing time for the digitized replications remains constant. Further analysis indicated that for more than 40 targets in the target array, new targets arrive in the area faster than the non-digitized system can process previously arrived targets. Therefore, new targets are placed on either, or both the FSO and LNO queues before processing. Shown in Figure 9 is a graph depicting the overall non-digitized base case CFF processing mean times for increasing target numbers, and the corresponding mean time the CFF spent in the FSO and LNO queue.

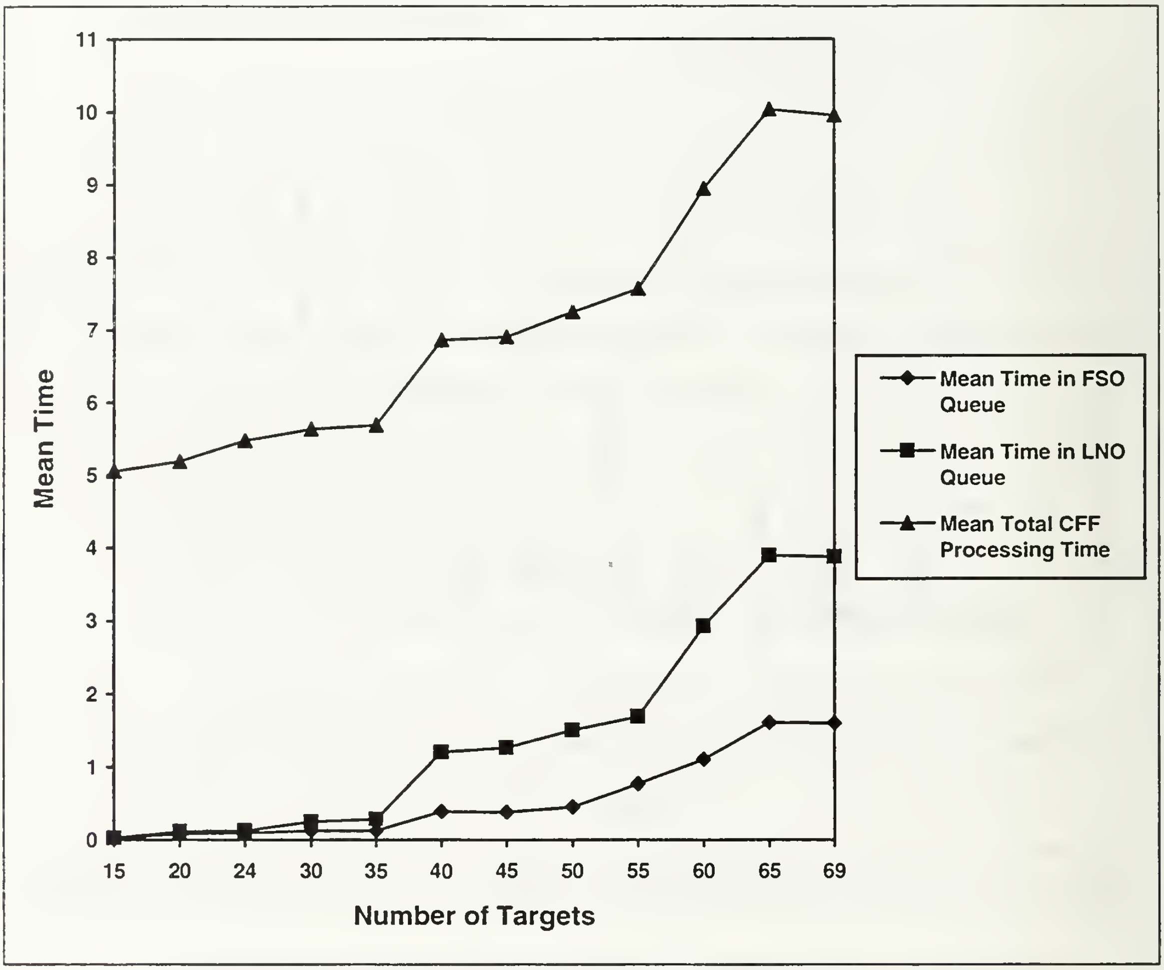

Figure 9. Comparison of Non-Digitized CFF Processing Queue Times, Base Case

Figure 9 shows that the difference between the LNO processing time and the Mean Total CFF Processing time remains basically constant over the range of targets. It is, in fact, the FSO and LNO queues which cause the value of Mean Total CFF Processing time to increase.

In the non-digitized base case + 25% replications, the mean CFF processing times are significantly larger than in the non-digitized base case. Shown in Figure 10 is a composite graph of the total mean processing time of the non-digitized, base case + 25%

replications, with comparison to the digitized case. The distribution of times in the non-digitized case are further represented by box plots. The absence of box plots for the digitized cases indicate the surplus capability of the digitized system.

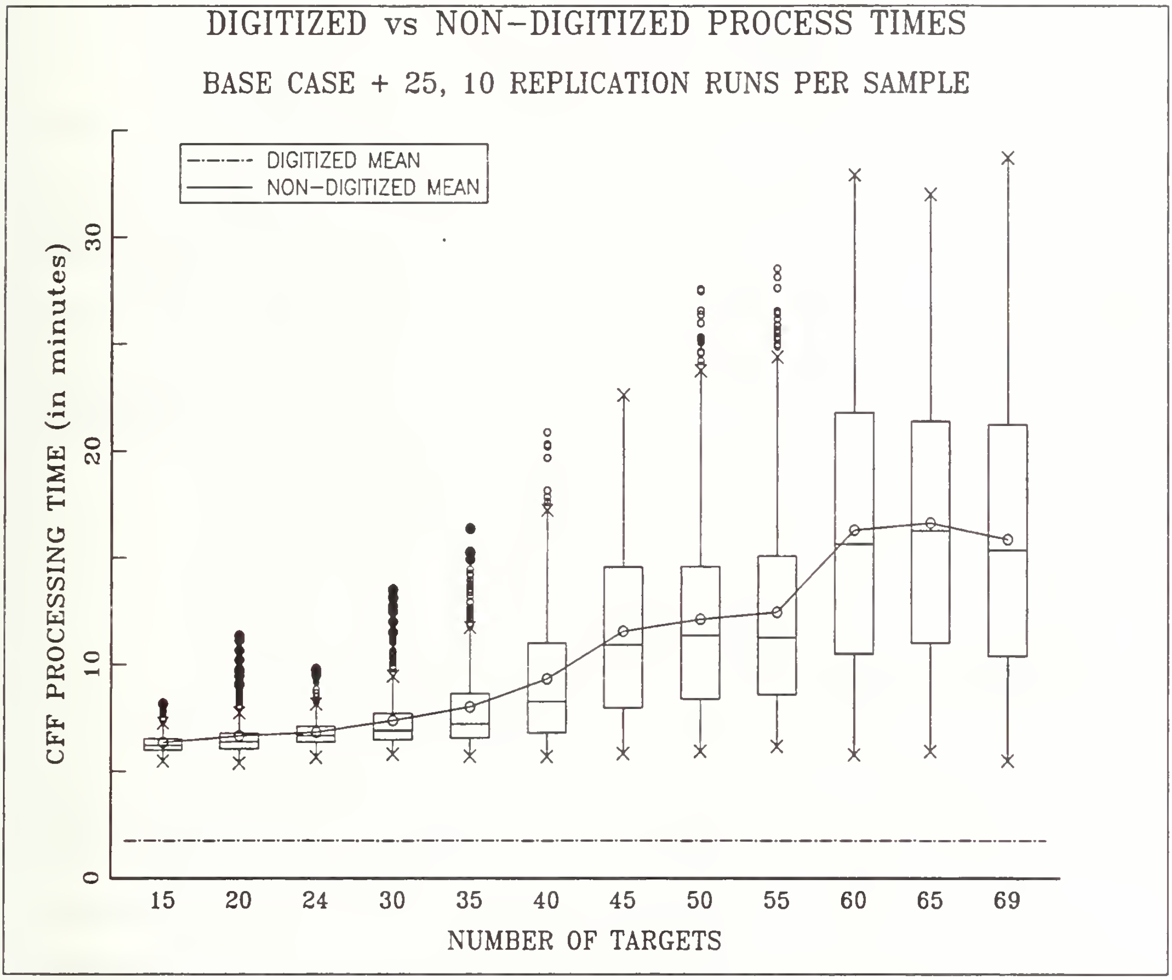

Figure 10. Composite Graph ,Digitized/Non-Digitized Target Processing Times, Base Case + 25%

In this case, with approximately 30 targets in the target array, the CFF processing time begins to increase dramatically for both mean and variability, showing the increasing tails of the box plots and the appearance of more outliers. As in the non-digitized base case, as the numbers of targets available for prosecution increase, the mean time a CFF spends in either, or both, the FSO and LNO queues dramatically increases, thereby increasing the total mean processing time. This result is shown in the graph in Figure 11.

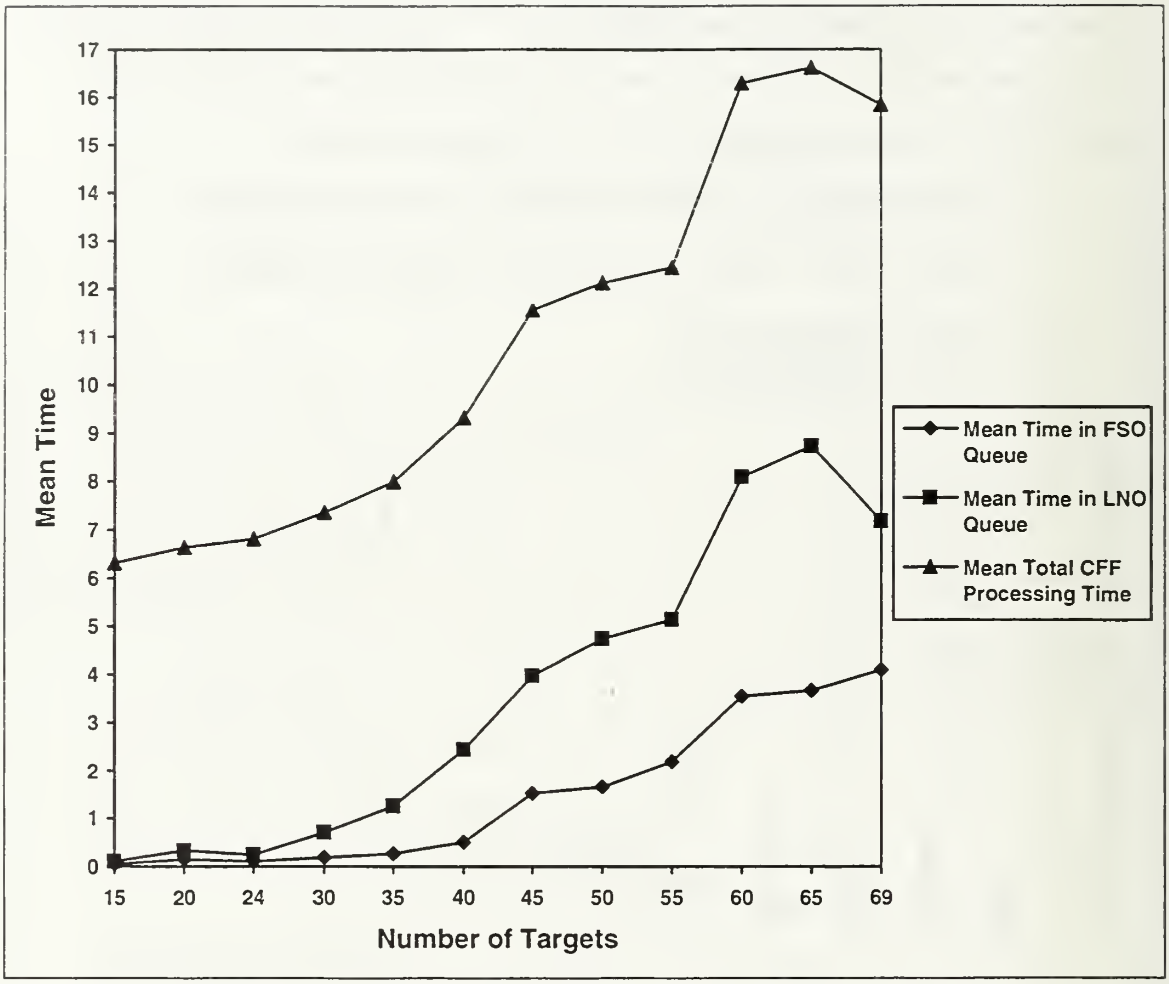

Figure 11. Comparison of Non-Digitized CFF Processing Queue Times, Base Case + 25%

Another question is, "If the number of targets that are available to be prosecuted remains constant, what would occur in a case where there is a greater supply of missiles than targets?" For this excursion from the base case, the number of targets was returned to its original value of 69 and the number of missiles was increased to 100. This change allowed more re-engagement of targets that were not destroyed by the first missile processed for that target. In the base case, the mean time a CFF spent in the FSO queue increased almost five minutes (1.6 to 6.5 minutes); time in the LNO queue increased over three minutes (3.9 to 7.3 minutes); mean total processing time increased from 9.9 to 15.1 minutes. For the base case + 25% the increases were even larger: 4.1 to 13.4 minutes in the FSO queue, 7.2 to 11.9 in the LNO queue, and 15.8 to 21.9 in total mean CFF processing time. While the increase in the number of available missiles means more missions can be fired, processing the CFFs for those missions swamps an already overburdened non-digitized system. Hence, the drastic increase in the CFF processing times for both the base case and base case + 25% scenarios. However, for both the base case and base case + 25% digitized scenarios, the processing time remained constant (1.45 minutes in the base case, 1.75 minutes in the base case + 25%), clearly indicating that the digitized system has not yet reached capacity. A matrix of all runs with mean times and standard deviations is located in Appendix N.

V. CONCLUSIONS

A. SUMMARY

While the simulation model developed here has some limitations, there are some definite benefits to such discrete time simulations:

- The overhead cost is inexpensive. Pascal is a low-priced software program, and not difficult to learn. It runs on standard DOS based computers currently present in an overwhelming majority of Army analysis agencies. The code is easily understood, even by those who have little experience with computer programming.

- The discrete time simulation approach provides a quick, reasonable answer to an existing problem. With minor adjustments to the programming code, the model easily becomes highly robust (see discussion below).

- The outcome from these initial simulation runs provides a firm basis for future and follow-on studies concerning the nature of the problem and possible changes to the system before production.

Examining the data presented in the previous section, several conclusions can be reached:

- The digitized system is far superior to the non-digitized system regardless of the number of targets.

- The non-digitized system's processing remains constant when target movement rates are slow (approximately 10 meters/second) or when a limited number of targets are present (approximately 40).

- Increasing the supply of missiles has a significant effect on non-digitized queue times. With fewer missiles than targets, after the first round impacts on a target and BDA is performed, there generally were no more missiles remaining to re-shoot the target if it was not completely destroyed. However, with more missiles, a CFF can be reinitiated on the target, thereby increasing the number of CFFs on an already overburdened system.

- The time a CFF spends in the FSO/LNO queues has the greatest impact on total CFF processing time. With more targets to process, increases in individual processing times, or more missiles than targets, the queues become bottlenecks that continue to accumulate CFFs.

- With the AFATDS being capable of processing multiple CFFs, and simultaneous CFF processing occurring at the brigade, platoon leader and battery levels, the total processing time is purely a function of how fast data can be manipulated and disseminated.

- The stress of continuous combat operations may have a significant effect on human processing abilities as seen in the non-digitized base case + 25% scenario. This stress could greatly impact total processing times for CFFs.

These conclusions are based upon the results of the simulation model which in itself has not been validated nor verified. Further testing of the model and its parameters would need to be made to come to more verifiable results.

B. LIMITATIONS AND ENHANCEMENTS

There are several limitations to the discrete time model. While they can be overcome they did cause some problems during the development of this thesis.

- Limitation of the Pascal language make programming difficult at times. With a limited allowable data segment (65,520 bytes), this restricts the number of variables that can be declared within a procedure. With the size of the data arrays, the data segment limitation can easily be reached. This causes the programmer to parse out global variables to several sub-unit programs, and can make the code difficult to follow at times.

- The programming language is not object-oriented in nature. While object oriented programming is possible in Pascal, it is not as powerful a language as C^{++} or MODSIM would be for developing this type of program. However, C and MODSIM can be difficult to understand, and MODSIM, while extremely powerful, is usually run on UNIX based systems that have substantially higher costs than normal DOS based hardware applications. PC versions of MODSIM exist, but are very expensive.

- Pascal can be very difficult to debug and remove run-time errors. The Pascal run-time library provides error messages, but these messages can be deceiving and difficult to trace, especially over numerous sub-programs and routines.

- No queue is depicted within the digitized C^3 system. While the new AFATDS system may be powerful, it is doubtful it can manage the volume of CFFs that could theoretically be placed on it. Additionally, there is no system of checks and balances depicted in the CSC diagrams. In a force that is seriously concerned with the possibilities of fratricide on the battlefield, not having some command and control headquarters wired into the decision loop for executing missile firing criteria is an error. The simulation model seeks to correct this by allowing no CFF to be executed without the tacit approval echoing down the chain of command to the battery. In the "do not fire by exception" policy, the battery could theoretically receive a fire mission from the AFATDS and execute that mission without the brigade cell or platoon leader ever receiving the firing data from the AFATDS. Should some command and control issue arise at brigade that would restrict missile flights (i.e., attack helicopters engaging deep targets), there are no provisions shown in the CSC report calling for explicit brigade approval for missile flights.

- Only one "super-launcher" is depicted in the simulation model. In reality, there would be several launchers situated in numerous locations over the friendly battle position to enhance survivability. This would require different ranges from each launcher to the target array, and cause the possibility of communications failures to occur while passing fire commands from the battery to gun level. Also, while it would seem that counter-battery fires would be difficult on these launchers, no launcher attrition was depicted, nor were the possibilities of "shoot-and-move" style tactics taken into consideration. These tactics would obviously render launchers inactive for the period of time they are moving, and unable to shoot. (This also raises the possibility of hip-shoots.)

- Finally, enemy targets were depicted as approaching the battlefield arrayed in a single file march column formation with doctrinal distances between each vehicle and maneuver element within the attacking force. In reality, the enemy will most likely attack on a broad front across numerous axes of advance, which only increases the command and control burden on the EFOGM system.

C. VARIATIONS AND MODEL CAPABILITIES

While there are some obvious limitations to the model, there are some inherent capabilities and variations of model runs which make this model highly robust and versatile. This thesis concentrated on only one aspect of the EFOGM system, the processing time for the two possible C^3 systems. However, several features of the model are worth mentioning:

- Missile characteristics can be adjusted and studied. The model allows for missile detections by enemy forces and evasion. While the probability of occurrence of these events in based on the author's professional judgment, "exact" probabilities based on other studies can easily be input to give estimates of missile successes while considering enemy air defense threats. Additionally, the probability of target damage based on a missile hit, the probability of a missile hit, and several other missile characteristics were all based on professional judgments of what they might be. Actual data from AMSAA or TEXCOM would only increase the validity of the model.

- Detections by sensors, while realistic, are based on relatively old detection theory formulas. New detection algorithms exist which would allow the detection portion of the simulation to be much more realistic. For example, the NVEOL (Night Vision Electro-Optical Laboratory) detection algorithm simulates the capabilities of image intensification and thermal sights which are not taken into account in this model. Target detections based on a more sophisticated detection algorithm could easily be fed to the simulation model, thereby increasing the realism.

- As the C^3 system for the EFOGM is further refined through testing new and more highly advanced technology, the simulation model provides a framework to test new capabilities for different outcomes.

This thesis demonstrates the potential of relatively simple, discrete-time simulation models to assist in performance estimation of undeveloped combat systems on the modern-day battlefield. Building on the principles of the stochastic state space, it provides analytic agencies, specifically, the U.S. Army Infantry School, the study sponsor, the ability to incorporate future technologies into existing combat models, or be used as a stand-alone model for data analysis. In light of today's quickly developing technology base, and the unpredictable nature of future conflicts, simulation modeling can only improve the ability of Army planners to prepare for future missions, and strengthen their commitment to provide the Army with the best equipment available.

APPENDIX A. DIAGRAM EXTENDED CLOSE BATTLEFIELD

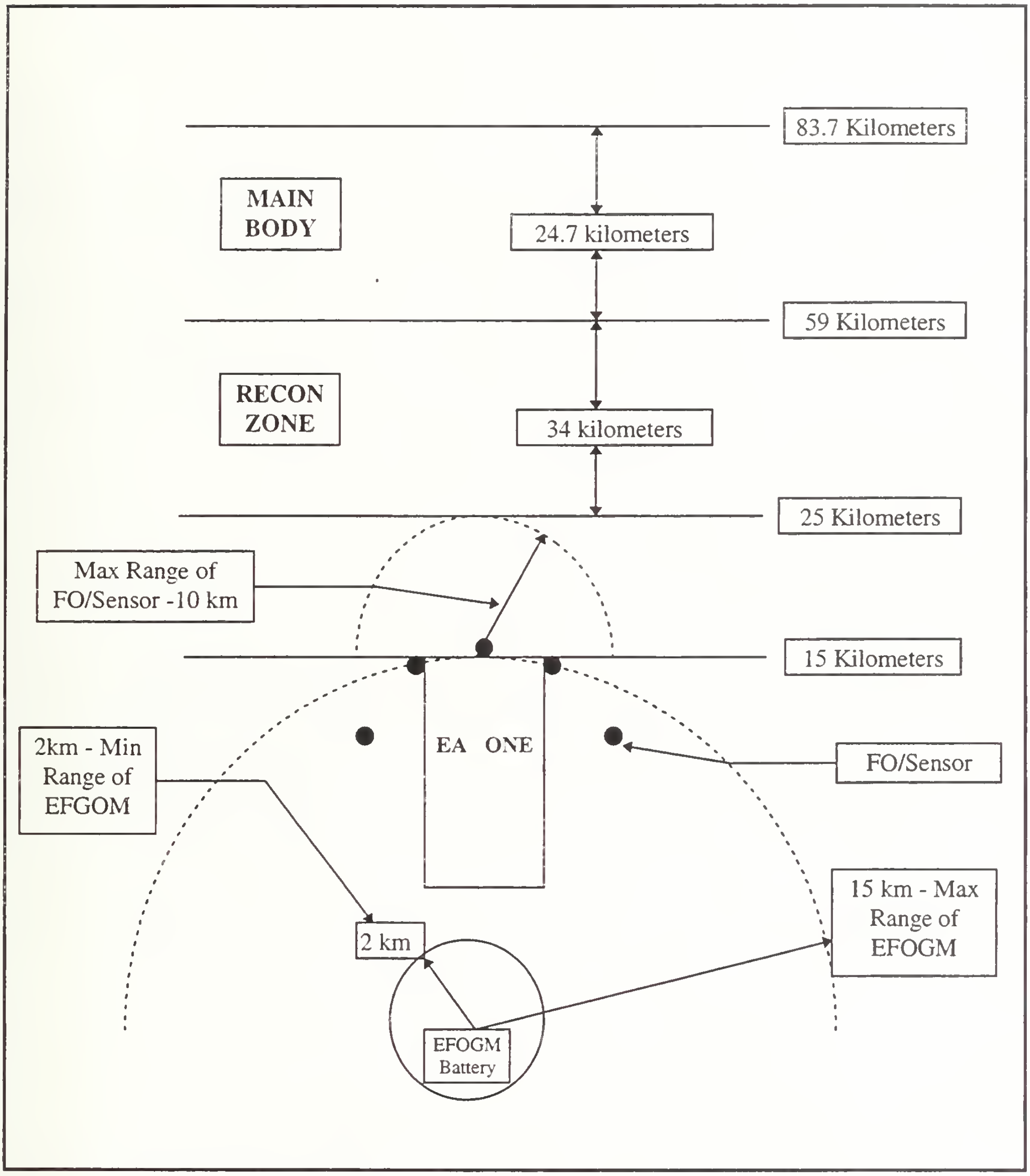

Figure 12. Diagram of Simulated ECB

APPENDIX B. STATE SPACE TRANSITION PROBABILITIES

The transition probabilities are based on the author's professional judgment. Refer to Figure 1 for graphical depiction of these state space descriptions.

State (i)	State Description	Transition State (j)	Transition Probability (Pij)
1	FO initialization	2 or 5	0.015, 0.985
2	FO Detected	3 or 5	0.15, 0.85
3	FO Destroyed	None	N/A
4	FO Not Destroyed	6	1.0
5	FO Undetected and not Destroyed	6	1.0
6	FO Searches	7 through j or 1	Should a detection be made, the transition will be made to the type of detected system in states 7 through j with probability = 1.0. However, if a detection is not made in the described time period, transition is back to state 1 with probability = 1.0.
7	Detect Recon asset	j + 1	1.0
8	Detect C^2 asset	j + 1	1.0
9	Detect ADA asset	j + 1	1.0
j	Detect jth asset	j + 1	1.0
j+1	FO transmits a CFF to the BDE or AFATDS	j + 2 or j + 3	0.01, 0.99
j+2	CFF not received by BDE or AFATDS	j + 2 or j + 3 or 1	The probability the FO makes contact with BDE/AFATDS on his next try is 0.95. Chance he fails to make contact again is 0.05. If the number of attempts cause the time standard to be exceeded, the FO quits, and returns to State 1 with probability = 1.0
j+3	CFF is received by BDE/AFATDS and processed by all subordinate elements	j + 4	1.0
j+4	EFOGM launch	j + 5, j + 6 or j + 8	0.01, 0.02, 0.97
j+5	EFOGM lost at launch (LAL)	None	N/A
j+6	EFOGM Misfires	j + 5, j +6, j +7 or j + 8	0.01, 0.05, 0.01,0.93

State (i)	State Description	Transition State (j)	Transition Probability (Pij)
j+7	DUD missile, select new missile and attempt re-fire	j + 5, j + 6 j + 8	0.01, 0.02, 0.97
j+8	Successful Launch	j + 9 or j + 10	0.05, 0.95
j+9	EFOGM detected in flight and engaged	j + 11 or j + 12	0.015, 0.985
j+10	EFOGM not detected in flight	j + 13 or j + 14	0.02, 0.98
j + 11	EFOGM Destroyed	None	N/A
j + 12	EFOGM Missed	j + 13 or j + 14	0.02, 0.98
j + 13	EFOGM Lost in flight (LIF)	None	N/A
j + 14	EFOGM acquires and locks onto target	j + 18 or j + 15	0.05, 0.95
j + 15	EFOGM Impacts on target	j + 16, j + 17	0.80, 0.20
j + 16	Target Destroyed	j + 23 or j + 24	0.01, 0.99
j + 17	Target not Destroyed | Target Impact	j + 19 through j + 22	0.90, 0.04, 0.05, 0.01
j + 18	EFOGM near misses target	j + 19 through j + 22	0.70, 0.15, 0.10, 0.05
j + 19	EFOGM causes Heavy Damage	j + 23 or j + 24	0.10, 0.90
j + 20	EFOGM causes Moderate Damage	j + 23 or j + 24	0.30, 0.70
j + 21	EFGOM causes Light Damage	j + 23 or j + 24	0.40, 0.60
j + 22	EFOGM causes No Damage (DUD warhead or impact too far away to cause any damage)	j + 23 or j + 24	0.60, 0.40
j + 23	FO re-shoots target	j + 1	1.0
j + 24	FO returns to searching	1	1.0

APPENDIX C. RANDOM NUMBER GENERATOR

This appendix contains the PASCAL code used within the simulation model to generate random U(0,1), normal and lognormal numbers. The U(0,1) random number generator is documented in the Law and Kelton text [Ref. 7, pp. 451-454]. The other random number generators were developed for this study in accordance with the text.

```
{      AUTHOR:     CPT David S. Pound

 ASSIGNMENT: Thesis
 WRITTEN:    9 April 1994
 REFERENCE:  Simulation Modeling and Analysis, 2d Ed.,Law and Kelton, pps.451-54.
 OBJECTIVE:  A random number generator for thesis simulation program with prime
 modulus multiplicative linear congruential generator:
                  Z[i] = ( 630360016 * Z[i-1] (MOD 2147483647),
 based on Marse and Roberts'portable FORTRAN random-number generator UNIRAN.
 Multiple (100) streams are supported, with seeds spaced 100,000 apart.
 Throughout, input argument Stream must be an Integer giving the desired stream
 number.  The initialization procedure RANDDF described below must be invoked
 before using the generator, in order to set the seeds for the 100 predefined streams.
 Usage: (Four procedures)
 1.  Before using the generator, it is required to initialize the routines by
     executing
             Randdf;
     This sets the initial seed values for all 100 streams in the array Zrng.
 2.  To obtain the next U[0,1] random number from stream STREAM, execute
             U := Rand(Stream)
     The Real variable U will contain the next random number.
 3.  To set the seed for stream STREAM to a desired value ZSET, execute
             Randst(Zset,Stream)
     where Zset must be an Integer constant or variable set to the desired seed
     a number between 1 and 2147483646 (inclusive).  Seeds for all 100 streams
     are given in the code, and must be initialized by invoking Randdf.
 4.  To get the current (most recently used) integer in the sequence being
     executed for stream STREAM into the Integer variable Zget, execute
             Zget = Randgt(Stream)
--------------------------BEGIN PROGRAM--------------------------------------}
Unit RandNumGen; {Ref: Simulation Modeling and Analysis, Law & Kelton, pp 451-54}
INTERFACE

VAR
   Zrng : ARRAY [1..100] of LongInt;
Procedure RANDDF;
Function RAND(Stream : LongInt) : Real;
Procedure Randst(Zset, Stream : LongInt);
Function Randgt(Stream : LongInt) : LongInt;
Function Seed: Word;
Function Normal(Mu,Sigma :Real) : Real;
Function LogNormal(Mu, Sigma :Real) : Real;
IMPLEMENTATION
uses CRT, DOS;
{-------------------------Set the seeds for all 100 Streams--------------------}
Procedure RANDDF;
  Begin
    Zrng[ 1]:=1973272912; Zrng[ 2]:= 281629770; Zrng[ 3]:=  20006270;
    Zrng[ 4]:=1280689831; Zrng[ 5]:=2096730329; Zrng[ 6]:=1933576050;
    Zrng[ 7]:= 913566091; Zrng[ 8]:= 246780520; Zrng[ 9]:=1363774876;
    Zrng[10]:= 604901985; Zrng[11]:=1511192140; Zrng[12]:=1933576050;
    Zrng[13]:= 824064364; Zrng[14]:= 150493284; Zrng[15]:= 242708531;
    Zrng[16]:=  75253171; Zrng[17]:=1964472944; Zrng[18]:=1202299975;
    Zrng[19]:= 233217322; Zrng[20]:=1911216000; Zrng[21]:= 726370533;
    Zrng[22]:= 403498145; Zrng[23]:= 993232223; Zrng[24]:=1103205531;
    Zrng[25]:= 762430696; Zrng[26]:=1922803170; Zrng[27]:=1385516923;
    Zrng[28]:=  76271663; Zrng[29]:= 413682397; Zrng[30]:= 726466604;
    Zrng[31]:= 336157058; Zrng[32]:=1432650381; Zrng[33]:=1120463904;
    Zrng[34]:= 595778810; Zrng[35]:= 877722890; Zrng[36]:=1046574445;
    Zrng[37]:=  68911991; Zrng[38]:=2088367019; Zrng[39]:= 748545416;
    Zrng[40]:= 622401386; Zrng[41]:=2122378830; Zrng[42]:= 640690903;
    Zrng[43]:=1774806513; Zrng[44]:=2132545692; Zrng[45]:=2079249579;
    Zrng[46]:=  78130110; Zrng[47]:= 852776735; Zrng[48]:=1187867272;
    Zrng[49]:=1351423507; Zrng[50]:=1645973084; Zrng[51]:=1997049139;
    Zrng[52]:= 922510944; Zrng[53]:=2045512870; Zrng[54]:= 898585771;
    Zrng[55]:= 243649545; Zrng[56]:=1004818771; Zrng[57]:= 773686062;
    Zrng[58]:= 403188473; Zrng[59]:= 372279877; Zrng[60]:=1901633463;
    Zrng[61]:= 498067494; Zrng[62]:=2087759558; Zrng[63]:= 493157915;
    Zrng[64]:= 597104727; Zrng[65]:=1530940798; Zrng[66]:=1814496276;
    Zrng[67]:= 536444882; Zrng[68]:=1663153658; Zrng[69]:= 855503735;
```

```
    Zrng[70]:=  67784357; Zrng[71]:=1432404475; Zrng[72]:= 619691088;
    Zrng[73]:= 119025595; Zrng[74]:= 880802310; Zrng[75]:= 176192644;
    Zrng[76]:=1116780070; Zrng[77]:= 277854671; Zrng[78]:=1366580350;
    Zrng[79]:=1142483975; Zrng[80]:=2026948561; Zrng[81]:=1053920743;
    Zrng[82]:= 786262391; Zrng[83]:=1792203830; Zrng[84]:=1494667770;
    Zrng[85]:=1923011392; Zrng[86]:=1433700034; Zrng[87]:=1244184613;
    Zrng[88]:=1147297105; Zrng[89]:= 539712780; Zrng[90]:=1545929719;
    Zrng[91]:= 190641742; Zrng[92]:=1645390429; Zrng[93]:= 264907697;
    Zrng[94]:= 620389253; Zrng[95]:=1502074852; Zrng[96]:= 927711160;
    Zrng[97]:= 364849192; Zrng[98]:=2049576050; Zrng[99]:= 638580085;
    Zrng[100]:= 547070247;
End; {Randdf}
{---------------------Generate the next Random Number------------------------}
Function RAND(Stream : LongInt) : Real;
CONST
   B2E15   =      32768;
   B2E16   =      65536;
   Modlus  = 2147483647;
   Mult1   =      24112;
   Mult2   =      26143;
VAR
   Hi15, Hi31, Low15, Lowprd, Ovflow, Zi : LongInt;
BEGIN
   {Generate the next random number}
   Zi:= Zrng[Stream];
   Hi15:= Zi DIV B2E16;
   Lowprd:= (Zi - Hi15*B2E16) * Mult1;
   Low15:= Lowprd DIV B2E16;
   Hi31:= Hi15*Mult1 + Low15;
   Ovflow:= Hi31 DIV B2E15;
   Zi:= (((Lowprd-Low15*B2E16)-Modlus) + (Hi31-Ovflow*B2E15)*B2E16) + Ovflow;
      If Zi < 0 THEN  Zi:= Zi + Modlus;
   Hi15:= Zi DIV B2E16;
   Lowprd:= (Zi - Hi15*B2E16)*Mult2;
   Low15:= Lowprd DIV B2E16;
   Hi31:= Hi15*Mult2 + Low15;
   Ovflow:= Hi31 DIV B2E15;
   Zi:= (((Lowprd-Low15*B2E16)-Modlus) + (Hi31-Ovflow*B2E15)*B2E16) + Ovflow;
      If Zi < 0 THEN  Zi:= Zi + Modlus;
   Zrng[Stream] := Zi;
   Rand:= (2*(Zi DIV 256) + 1)/16777216.0;
End; {Rand}
{----------------Set the current Zrng for stream STREAM to Zset---------------}
Procedure Randst(Zset, Stream :LongInt);
Begin
     Zrng[Stream]:= Zset;
End;
{----------------Return the current Zrng for stream STREAM--------------------}
Function Randgt(Stream : LongInt) : LongInt;
Begin
     Randgt:= Zrng[Stream];
End;
{----------------------------SEED GENERATOR FOR RNG---------------------------------------
------}
Function Seed: Word;
Var Hour,Minute,Second,Sec100: Word;
Begin
  GetTime(Hour,Minute,Second,Sec100);
  SEED:= Second;
end;
{----------------RETURN A NORMAL(MU,SIGMA) RANDOM VARIABLE--------------------}
Function Normal(Mu,Sigma: Real) : Real;
Var U1,U2,V1,V2,W,X,Y :Real;
    Done              :Boolean;
Begin
  DONE:= FALSE;
  REPEAT
   U1:= RAND(SEED);
   U2:= RAND(SEED);
   V1:= 2*U1-1;
```

```
   V2:= 2*U2-1;
   W:= SQR(V1) + SQR(V2);
     If W < 1.0 then begin
        Y:= SQRT((-2.0*ln(W))/W);
        Done:= True;
     end; {if}
  UNTIL DONE;
   X:= V1*Y;
   Normal:= Mu + Sigma*X;
End; {Normal}
{----------------RETURN A LOGNORMAL(MU,SIGMA) RANDOM VARIABLE--------------------}
Function LogNormal(Mu,Sigma: Real) : Real;
Var U1,U2,V1,V2,W,X,Y,Z,Mu2,SigmaSqr : Real;
    Done                             : Boolean;
Begin
  Done:=False;
  Mu2:= Ln( SQR(MU)/ SQRT( SQR(SIGMA) + SQR(MU) )   );
  SigmaSqr:= Ln( ( SQR(SIGMA) + SQR(MU) ) / SQR(MU) );
  Z:= NORMAL(MU2, SQRT(SIGMASQR));
  LogNormal:= Exp(Z);
End; {LogNormal}
{---------------------------------MAIN----------------------------------------}
Begin
end.
```

APPENDIX D. VERIFICATION OF RANDOM NUMBER GENERATOR

The graphs and statistical analysis shown in this appendix were used for confirmation of the normal and lognormal random number generators used in the simulation program, and were created by *AGSS*.

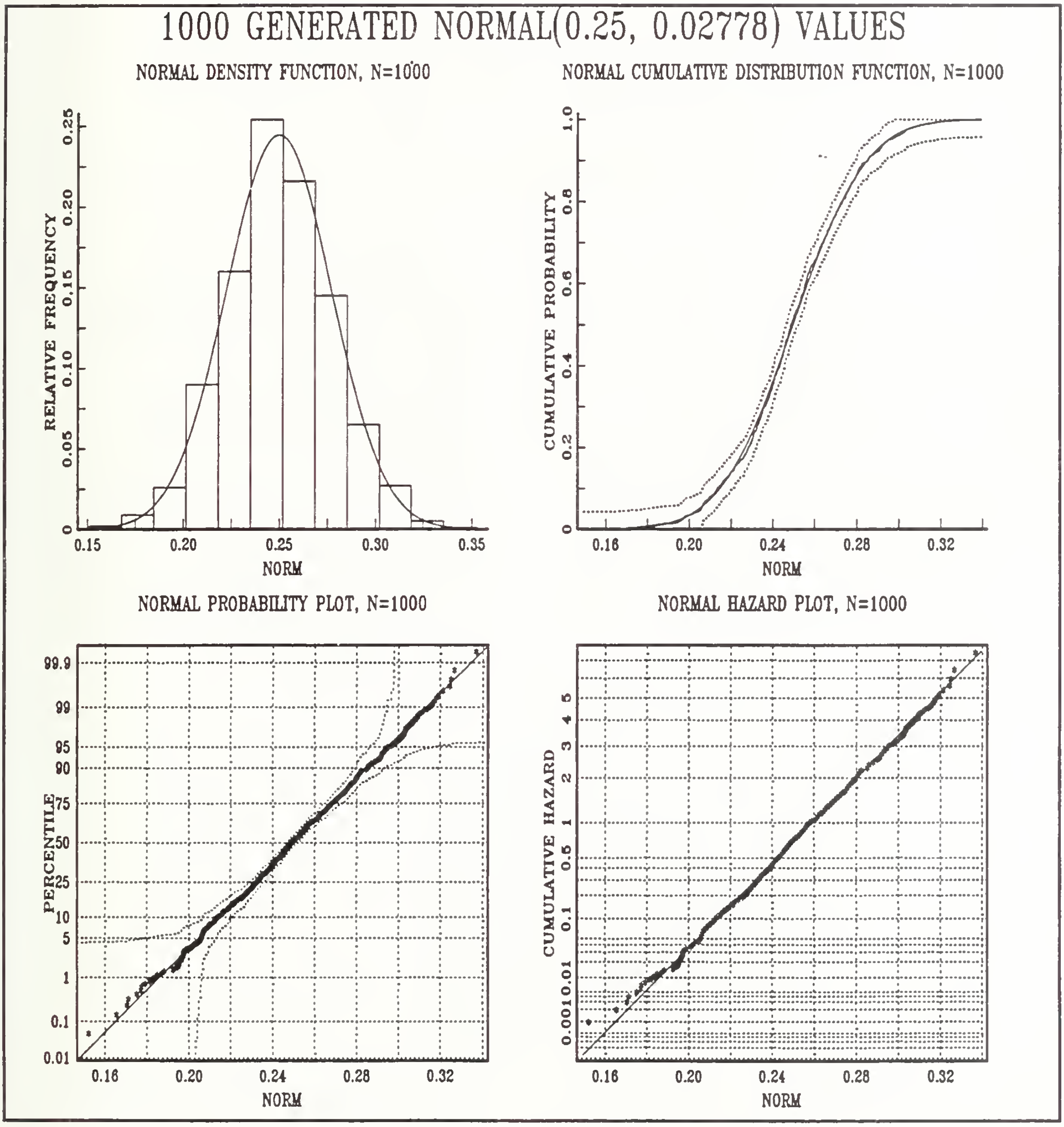

Figure 13. Normal Graphical Analysis of Randomly Generated Numbers

ANALYSIS OF NORMAL DISTRIBUTION FIT

```
DATA         : NORM
SELECTION    : ALL
X AXIS LABEL: NORM
SAMPLE SIZE : 1000
CENSORING    : NONE
FREQUENCIES : 1
EST. METHOD : MAXIMUM LIKELIHOOD
CONF METHOD : EXACT
```

		CONF. INTERVALS (95 PERCENT)		COVARIANCE MATRIX OF PARAMETER ESTIMATES	
PARAMETER	ESTIMATE	LOWER	UPPER	MU	SIGMA
MU	0.24971	0.24801	0.25141	7.5019E-7	0.000E0
SIGMA	0.02739	0.026253	0.02866	0.0000E0	3.751E-7

LOG LIKELIHOOD FUNCTION AT MLE = 2178.7

	SAMPLF	FITTED
MEAN :	0.24971	0.24971
STD DEV :	0.027403	0.02739
SKEWNESS:	-0.0097735	0
KURTOSIS:	3.0932	3

* BASED ON MIDPOINTS OF FINITE INTERVALS

PERCFNTILES	SAMPLE	FITTED
5:	0.2058	0.20465
10:	0.21345	0.2146
25:	0.2324	0.23124
50:	0.2486	0.24971
75:	0.268	0.26818
90:	0.28515	0.28482
95:	0.2949	0.294¯7

GOODNESS OF FIT TESTS

```
CHI-SQUARE : 5.3325
  DEG FREED: 7
  SIGNIF   : 0.61946
KOLM-SMIRN : 0.021278
  SIGNIF   : 0.7558
CRAMER-V M : 0.077831
  SIGNIF   :  > .15
ANDER-DARL : 0.4376
  S GNIF   :  > .15
```

KS, AD, AND CV SIGNIF. LEVELS NOT EXACT WITH ESTIMATED PARAMETERS.

NOTE: A SMALL SIGNIFICANCE LEVEL (EG. P≤.01) INDICATES LACK OF FIT

CHI-SQUARE GOODNESS OF FIT TABLE

LOWER	UPPER	OBS	EXP	O-E	((O-E)*2)÷E
-INF.	0.1846	11	8.7232	2.2768	0.59426
0.1846	0.20138	26	30.104	-4.1044	0.55958
0.20138	0.21816	90	85.884	4.1158	0.19724
0.21816	0.23495	160	170.22	-10.216	0.61318
0.23495	0.25173	254	234.43	19.568	1.6333
0.25173	0.26851	216	224.4	-8.3992	0.31438
0.26851	0.28529	145	149.28	-4.2813	0.12279
0.28529	0.30207	65	69.007	-4.0071	0.23268
0.30207	0.31886	27	22.159	4.8412	1.0577
0.31886	+INF.	6	5.7934	0.20663	0.0073696
TOTAL		1000	1000		5.3325

Figure 14. Normal Statistical Analysis of Randomly Generated Numbers

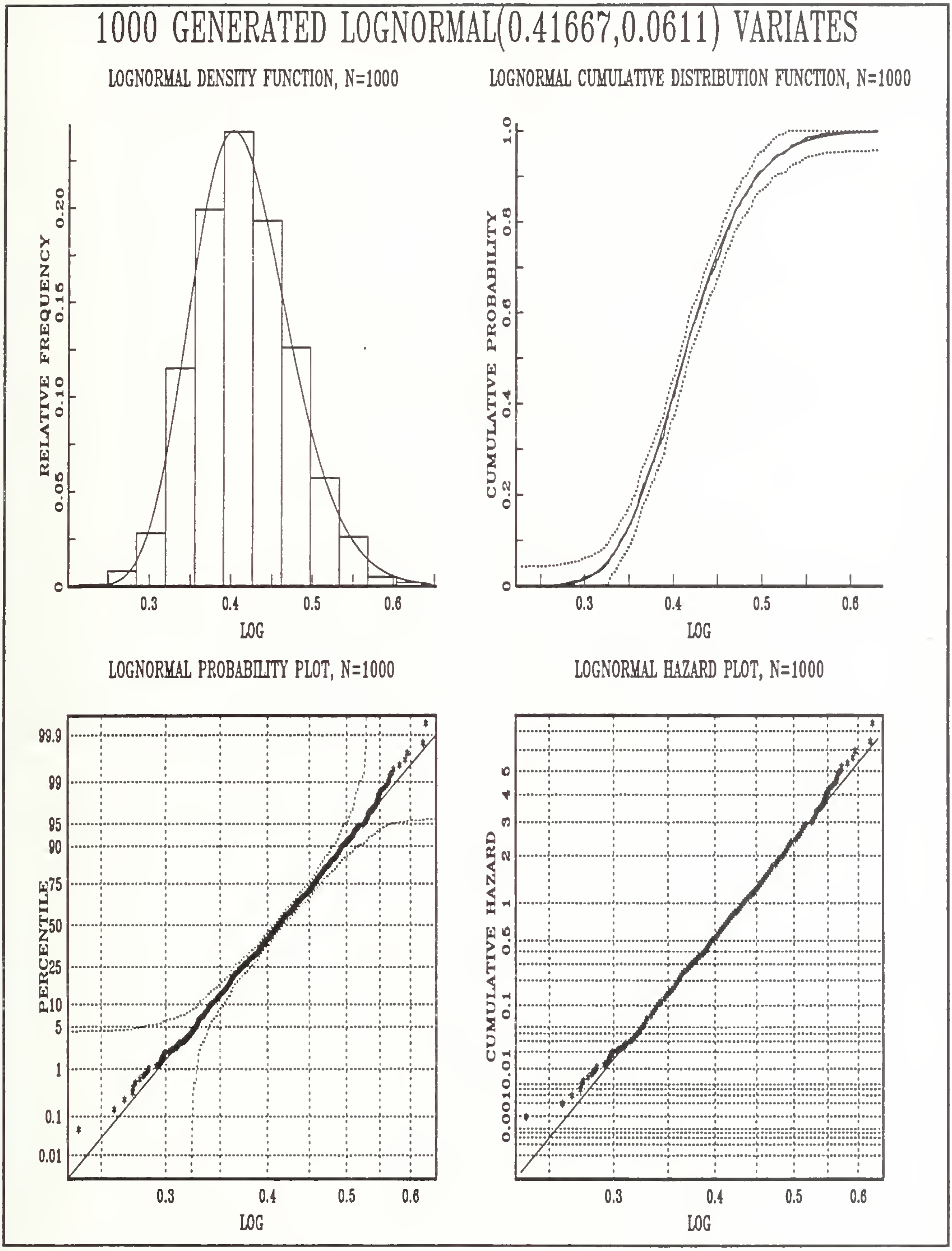

Figure 15. Lognormal Graphical Analysis of Randomly Generated Numbers

ANALYSIS OF LOGNORMAL DISTRIBUTION FIT

DATA : LOG
SELECTION : ALL
X AXIS LABEL: LOG
SAMPLE SIZE : 1000
CENSORING : NONE
FREQUENCIES : 1
EST. METHOD : MAXIMUM LIKELIHOOD
CONF METHOD : EXACT

		CONF. INTERVALS (95 PERCENT)		COVARIANCE MATRIX OF PARAMETER ESTIMATES	
PARAMETER	ESTIMATE	LOWER	UPPER	MU	SIGMA
MU	-0.8883	-0.89729	-0.87932	0.000020995	0
SIGMA	0.1449	0.13888	0.15162	0	0.000010497

LOG LIKELIHOOD FUNCTION AT MLE = 1401.1

	SAMPLE	FITTED
MEAN :	0.41566	0.4157
STD DEV :	0.059929	0.06055
SKEWNESS:	0.2737	0.44007
KURTOSIS:	2.9854	3.3463

* BASED ON MIDPOINTS OF FINITE INTERVALS

PERCENTILES	SAMPLE	FITTED
5:	0.32665	0.32411
10:	0.3403	0.34163
25:	0.37205	0.37307
50:	0.41185	0.41135
75:	0.4557	0.45357
90:	0.49305	0.4953
95:	0.5246	0.52209

GOODNESS OF FIT TESTS

CHI-SQUARE :	7.9602
DEG FREED:	8
SIGNIF :	0.43737
KOLM-SMIRN :	0.020521
SIGNIF :	0.79367
CRAMER-V M :	0.048731
SIGNIF :	> .15
ANDER-DARL :	0.32735
SIGNIF :	> .15

KS, AD, AND CV SIGNIF. LEVELS NOT EXACT WITH ESTIMATED PARAMETERS.

NOTE: A SMALL SIGNIFICANCE LEVEL (EG. P≤.01) INDICATES LACK OF FIT

CHI-SQUARE GOODNESS OF FIT TABLE

LOWER	UPPER	OBS	EXP	O-E	((O-E)*2)÷E
-INF.	0.28429	9	5.3893	3.6107	2.4191
0.28429	0.31983	28	35.812	-7.8116	1.7039
0.31983	0.35536	115	115.1	-0.10135	0.000089245
0.35536	0.3909	199	206.12	-7.121	0.24601
0.3909	0.42644	240	235.71	4.2893	0.078055
0.42644	0.46197	193	190.28	2.7187	0.038843
0.46197	0.49751	126	116.89	9.1094	0.7099
0.49751	0.53305	57	57.85	-0.85013	0.012493
0.53305	0.56858	26	24.101	1.8989	0.14961
0.56858	0.60412	5	8.7464	-3.7464	1.6047
0.60412	+INF.	2	3.9966	-1.9966	0.99744
TOTAL		1000	1000		7.9602

Figure 16. Lognormal Graphical Analysis of Randomly Generated Numbers

APPENDIX E. PROBABLISTIC TIME DISTRIBUTIONS

The figures in this appendix depict the command and control sequence and timeline distributions for the digitized and non-digitized simulations.

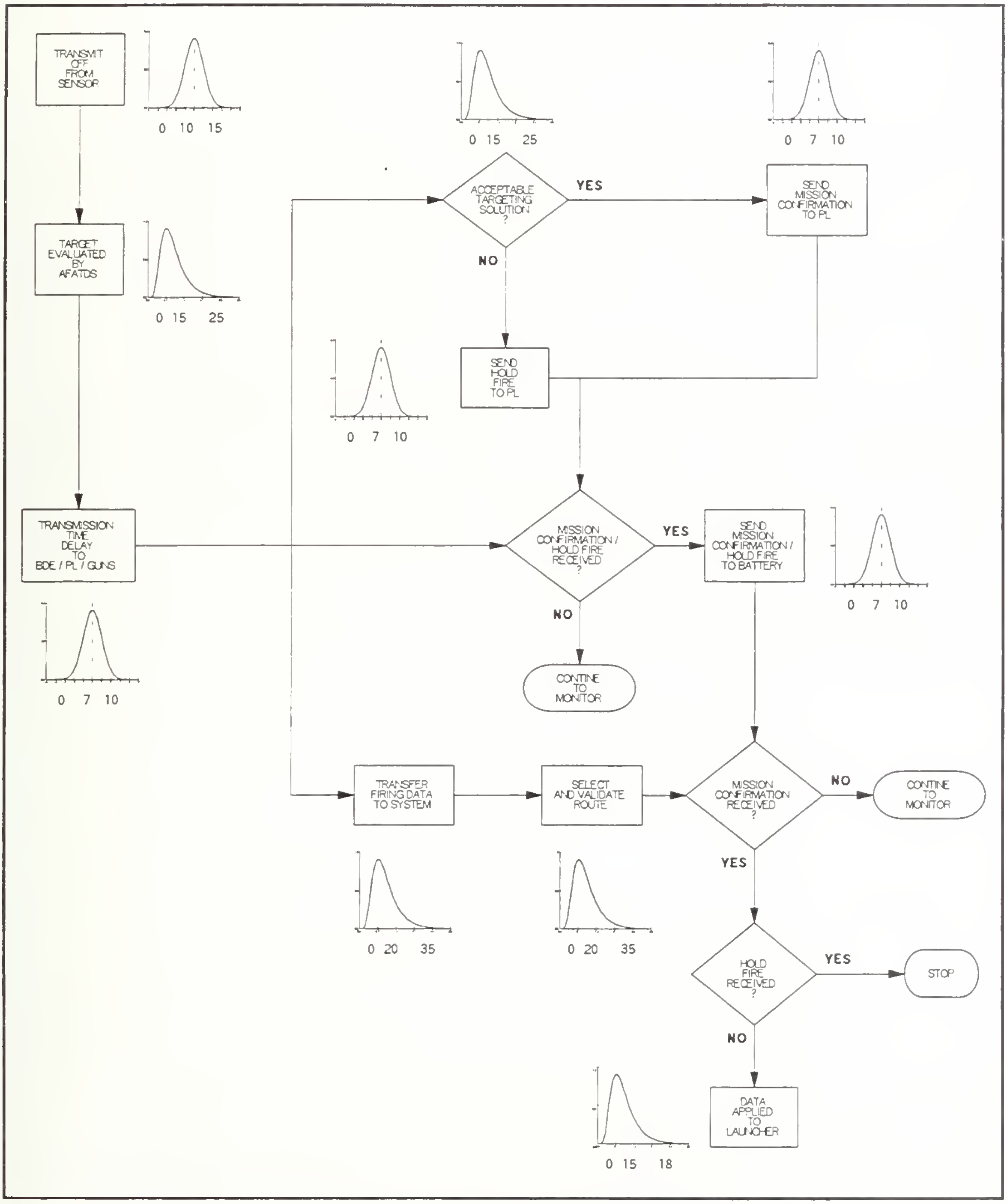

Figure 17. Digitized C2 Sequence and Timeline Distribution

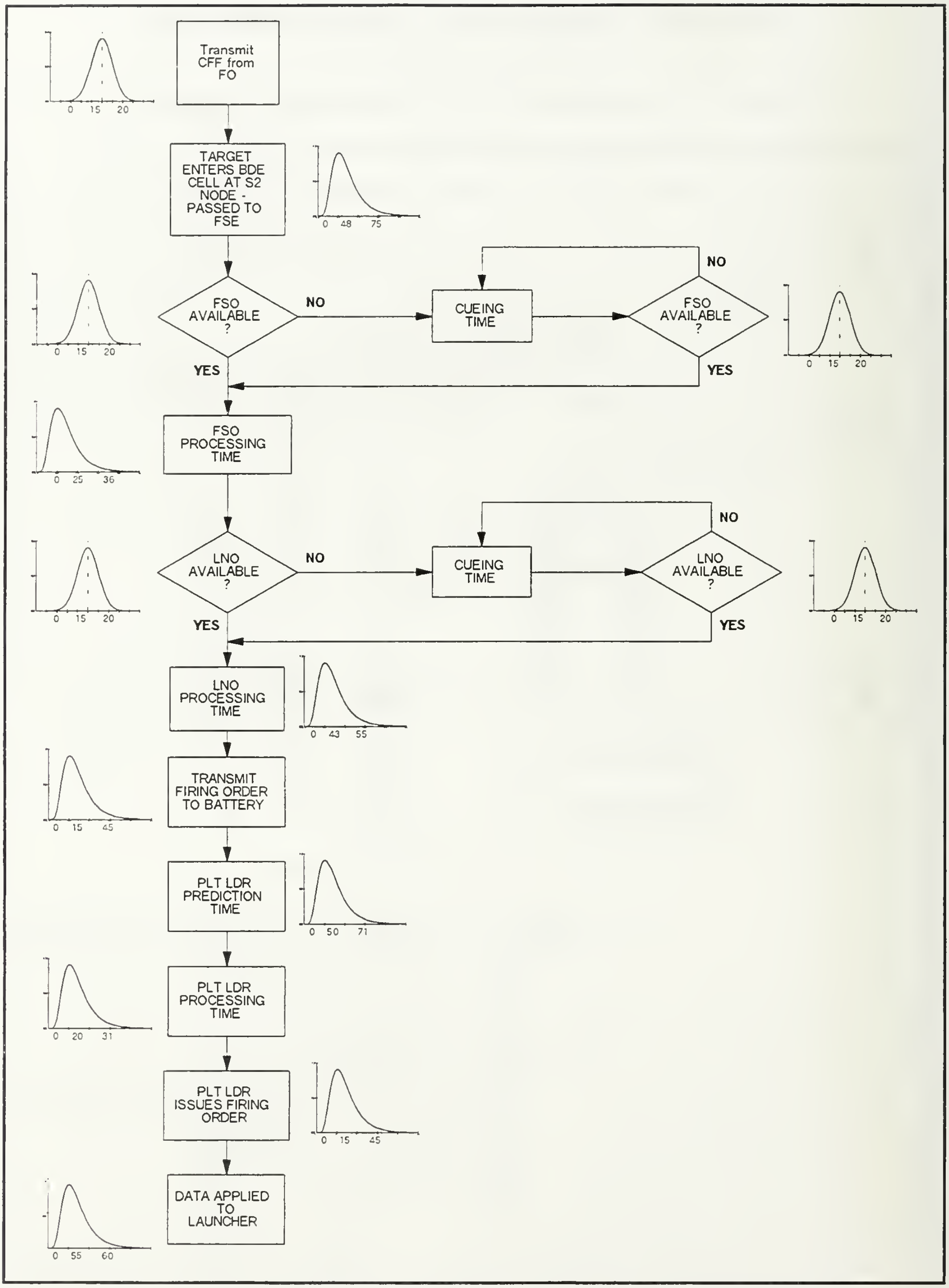

Figure 18. Non-Digitized C2 Sequence and Timeline Distributions

APPENDIX F. INPUT DATA TEXT FILE

Modifications to the text file shown in this appendix allow the user to change parameters within the model execution.

Data Text File

```
{1. Number of ave of approach into EA. USED IN ACQ TIME FUNCTION}
2.0
{2. Ave height of vegetation in HRS. Used in Acquisition Time Function}
1.5
{3. Maximum time in minutes FO spends SEARCHING before reinitialization}
5.0
{4. RATE OF MARCH OF ENEMY VEHICLES IN meters per second}
5.55
{5. EFOGM VELOCITY IN meters per second}
122.0
{6. MAX EFOGM RANGE IN Kilometers}
15.0
{7. EXTRA TIME FOR EACH ADDITIONAL RADIO CONTACT ATTEMPT IN MINUTES}
0.0833
{8. PROBABILITY OF FO DETECTION BY THE ENEMY}
0.015
{9.  PROBABILITY OF FO DESTRUCTION GIVEN DETECTION BY ENEMY}
0.15
{10.  SECTOR OF SCAN FOR OBSERVER/SENSORS IN DEGREES}
120.0
{11.  SIZE OF FIELD OF VIEW OF OBSERVER/SENSOR IN DEGREES}
45.0
{12.  MEAN TIME IN MINUTES TO XMIT RADIO CALL TO BDE HQ FROM OBSERVER}
0.25
{13.  3 SIGMA STD DEV IN MINUTES OF TIME REQD TO XMIT RADIO CALL TO BDE HQ FROM FO}
0.02778
{14.  NUMBER OF TIMES FO WILL ATTEMPT COMMO WITH BDE BEFORE GIVING UP}
12
{15.  MEAN TIME IN MINUTES FOR BDE RTO TO PROCESS CFF FROM FO}
0.8
{16.  3 SIGMA STD DEV IN MINUTES FOR BDE RTO TO PROCESS CFF FROM FO}
0.15
{17.  MEAN TIME IN MINUTES FOR RTO TO CHECK THE STATUS OF FSO}
0.25
{18.  3 SIGMA STD DEV IN MINUTES FOR RTO TO CHECK THE STATUS OF FSO}
0.02778
{19.  MEAN TIME IN MINUTES FOR FSO TO PROCESS CFF}
0.41667
{20.  3 SIGMA STD DEV IN MINUTES FOR FSO TO PROCESS CFF}
0.0611
{21.  MEAN TIME IN MINUTES TO CHECK ON EFOGM C2 CELL}
0.25
{22.  3 SIGMA STD DEV IN MINUTES TO CHECK ON EFOGM C2 CELL}
0.02778
{23.  MAX PROCESSING TIME IN MINUTES BEFORE REACHING THE EFOGM LNO THAT A CFF IS CANCELED
BY FSO/LNO}
12.0
{24.  TIME IN MINUTES FOR EFOGM LNO TO DETERMINE IF TARGET HAS ALREADY BEEN PROCESSED}
0.25
{25.  MEAN TIME IN MINUTES FOR EFOGM LNO TO PROCESS CFF}
0.71667
{26.  3 SIGMA STD DEV IN MINUTES FOR EFOGM LNO TO PROCESS CFF}
0.0667
{27.  MEAN TIME IN MINUTES FOR EFOGM C2 CELL TO XMIT FIRING ORDER TO BATTERY}
0.25
{28.  3 SIGMA STD DEV IN MINUTES FOR EFOGM C2 CELL TO XMIT FIRING ORDER TO BATTERY}
```

```
0.1667
{29.  MEAN TIME IN MINUTES FOR PLT LDR TO MAKE PREDICTION}
0.833
{30.  3 SIGMA STD DEV IN MINUTES FOR PLT LDR TO MAKE PREDICTION}
0.11667
{31.  MEAN TIME IN MINUTES FOR PLT LDR TO PROCESS CFF}
0.333
{32.  3 SIGMA STD DEV IN MINUTES FOR PLT LDR TO PROCESS CFF}
0.06111
{33.  MEAN TIME IN MINUTES FOR PLT LDR TO XMIT FIRING ORDER TO SQDS}
0.25
{34.  3 SIGMA STD DEV FOR PLT LDR TO XMIT FIRING ORDER TO SQDS}
0.1667
{35.  MEAN TIME IN MINUTES FOR GUNNER TO APPLY DATA TO LAUNCHER}
0.91667
{36.  3 SIGMA STD DEV IN MINUTES FOR GUNNER TO APPLY DATA TO LAUNCHER}
0.02778
{37.  TIME IN MINUTES TO GUNNER TO EXECUTE MISFIRE PROCEDURES}
0.3333
{38.  TIME IN MINUTES FOR GUNNER TO SELECT,ARM,INITAILIZE NEW MISSILE IF DUD OCCURS}
0.5
{39.  TIME IN MINUTES FOR FO TO EVALUATE BDA AND DECIDE ON COURSE OF ACTION}
0.5
{40.  transition probability from state 11 to state 12}
0.01
{41.  transition probability from state 12 to state 12}
0.05
{42.  transition probability from state 14 to state 16}
0.01
{43.  transition probability from state 16 to state 16}
0.05
{44.  transition probability from state 18 to state 19}
0.01
{45.  transition probability from state 18 to state 20}
0.02
{46.  transition probability from state 20 to state 19}
0.01
{47.  transition probability from state 20 to state 20}
0.01
{48.  transition probability from state 20 to state 21}
0.05
{49.  transition probability from state 21 to state 19}
0.01
{50.  transition probability from state 21 to state 20}
0.02
{51.  transition probability from state 22 to state 23}
0.05
{52.  transition probability from state 24 to state 27}
0.02
{53.  transition probability from state 23 to state 25}
0.015
{54.  transition probability from state 26 to state 27}
0.02
{55.  transition probability from state 28 to state 32}
0.1
{56.  transition probability from state 29 to state 31}
0.2
{57.  transition probability from state 31 to state 36}
0.01
{58.  transition probability from state 31 to state 35}
0.05
{59.  transition probability from state 31 to state 34}
0.04
{60.  transition probability from state 32 to state 36}
0.1
{61.  transition probability from state 32 to state 35}
0.2
{62.  transition probability from state 32 to state 34}
0.4
{63.  transition probability from state 30 to state 37}
0.01
{64.  transition probability from state 33 to state 37}
0.10
```

{65. transition probability from state 34 to state 37}
0.3
{66. transition probability from state 35 to state 37}
0.4
{67. transition probability from state 36 to state 38}
0.4
{68. MEAN TIME IN MINUTES FOR OBSERVER TO XMIT CFF TO AFATDS}
0.1667
{69. STD DEV IN MINUTES FOR OBSERVER TO XMIT CFF TO AFATDS}
0.0278
{70. MEAN TIME IN MINUTES FOR AFATDS TO EVAL TGT DATA}
0.25
{71. STD DEV IN MINUTES FOR AFATDS TO EVAL TGT DATA}
0.0556
{72. MEAN TIME IN MINUTES FOR AFATDS TO XMIT DATA TO BDE/PL/GUNS}
0.1167
{73. STD DEV IN MINUTES FOR AFATDS TO XMIT DATA TO BDE/PL/GUNS}
0.01667
{74. MEAN TIME IN MINUTES FOR BDE TO DETERMINE IF GOOD TGTING SOLN}
0.25
{75. STD DEV IN MINUTES FOR BDE TO DETERMINE IF GOOD TGTING SOLN}
0.0556
{76. MEAN TIME IN MINUTES FOR BDE TO SEND CONFIRMATION TO PL}
0.1167
{77. STD DEV IN MINUTES FOR BDE TO SEND CONFIRMATION TO PL}
0.01667
{78. MEAN TIME IN MINUTES FOR PL TO SEND CONFIRMATION TO GUNS}
0.11667
{79. STD DEV IN MINUTES FOR PL TO SEND CONFIRMATION TO GUNS}
0.01667
{80. MEAN TIME IN MINUTES FOR GUNNER TO XFER DATA TO SYSTEM}
0.333
{81. STD DEV IN MINUTES FOR GUNNER TO XFER DATA TO SYSTEM}
0.0833
{82. MEAN TIME IN MINUTES FOR GUNNER TO SELECT AND VALIDATE ROUTE}
0.333
{83. STD DEV IN MINUTES FOR GUNNER TO SELECT AND VALIDATE ROUTE}
0.0833
{84. MEAN TIME IN MINUTES FOR GUNNER TO APPLY DATA TO LAUNCHER}
0.25
{85. STD DEV IN MINUTES FOR GUNNER TO APPLY DATA TO LAUNCHER}
0.01667

APPENDIX G. TARGET DATA FILE

The following table provides the data incorporated into the input text files. It provides the data only for the high value targets located within HRS 33.5 and defined by the DBBL. The data contain values for the ranges from each high value target to each of the five sensor/FOs used in the simulation, as well as the ranges to the EFOGM launcher. Target height is provided as an input to the DYNTACS detection algorithm (discussed in Appendix F). See the input text files for formatting.

TARGET NUMBER	TARGET DESCRIPTION	POSITION IN ATTACK COLUMN	INITIAL RANGE TO SENSORS 1-3 (km)	INITIAL RANGE TO SENSORS 4-5 (km)	INITIAL RANGE TO EFOGM BATTERY (km)	TARGET HEIGHT (m)
1	RECON CO BRDM	4 KM BACK IN RECON ELEMENT	9.00	12.00	24.00	2.31
2	RECON CO TGT ACQ BTR60	4 KM BACK IN RECON ELEMENT	9.00	12.00	24.00	2.31
3	ZSU/23-4 #1	200 m BACK IN 1ST MRC	39.20	42.20	57.20	3.75
4	ZSU/23-4 #2	250 m BACK IN 1ST MRC	39.25	42.25	57.25	3.75
5	ZSU/23-4 #3	300 m BACK IN 1ST MRC	39.30	42.30	57.30	3.75
6	MRC 1 CDR BMP	350 m BACK IN 1ST MRC	39.35	42.35	57.35	2.15
7	ZSU/23-4 #4	600 m BACK IN 1ST MRC	39.60	42.60	57.60	3.75
8	ZSU/23-4 #5	650 m BACK IN 1ST MRC	39.65	42.65	57.65	3.75
9	ZSU/23-4 #6	700 m BACK IN 1ST MRC	39.70	42.70	57.70	3.75
10	SA-13/1 ON MTLB CHASSIS	750 m BACK IN 1ST MRC	39.75	42.75	57.75	1.87
11	SA-13/2 ON MTLB CHASSIS	800 m BACK IN 1ST MRC	39.80	42.80	57.80	1.87
12	SA-13/3 ON MTLB CHASSIS	850 m BACK IN 1ST MRC	39.85	42.85	57.85	1.87
13	SA-13/4 ON MTLB CHASSIS	900 m BACK IN 1ST MRC	39.90	42.90	57.90	1.87
14	MRB CDR IN BMP	1150 m BACK IN 1ST MRB	40.05	43.05	58.05	2.15
15	ARTY MOBILE RECON POST "SMALL FRED"	1250 m BACK IN 1ST MRB	40.15	43.15	58.15	2.15
16	MRC 2 CDR BMP	1800 m BACK IN 1ST MRB	40.70	43.70	58.70	2.15
17	MRC 3 CDR BMP	2450 m BACK IN 1ST MRB	41.35	44.35	59.35	2.15

TARGET NUMBER	TARGET DESCRIPTION	POSITION IN ATTACK COLUMN	INITIAL RANGE TO SENSORS 1-3 (km)	INITIAL RANGE TO SENSORS 4-5 (km)	INITIAL RANGE TO EFOGM BATTERY (km)	TARGET HEIGHT (m)
18	1st D-30 HOW BTRY FDC - BTR 60	2900 m BACK IN 1ST MRB	41.80	44.80	59.80	2.31
19	D-30 HOW BN TOC - BTR 60	3250 m BACK IN 1ST MRB	42.15	45.15	60.15	2.31
20	2nd D-30 HOW BTRY FDC - BTR 60	3300 m BACK IN 1ST MRB	42.20	45.20	60.20	2.31
21	3rd D-30 HOW BTRY FDC - BTR 60	3650 m BACK IN 1ST MRB	42.55	45.55	60.55	2.31
22	MRC 1 CDR BMP	250 m BACK IN 2ND MRB	44.55	47.55	62.55	2.15
23	MRB CDR BMP	650 m BACK IN 2ND MRB	45.00	48.00	63.00	2.15
24	ARTY MOBILE RECON POST "SMALL FRED"	750 m BACK IN 2ND MRB	45.10	48.10	63.10	2.15
2[illegible]	MRC 2 CDR BMP	1300 m BACK IN 2ND MRB	45.65	48.65	63.65	2.15
2[illegible]	MRC 3 CDR BMP	1950 m BACK IN 2ND MRB	46.30	4[illegible].30	64.30	2.15
27	1st D-30 HOW BTRY FDC - BTR 60	2400 m BACK IN 2ND MRB	46.75	49.75	64.75	2.31
28	D-30 HOW BN TOC - BTR 60	2750 m BACK IN 2ND MRB	47.10	50.10	65.10	2.31
29	2nd D-30 HOW BTRY FDC - BTR 60	2800 m BACK IN 2ND MRB	47.15	50.15	65.15	2.31
30	3rd D-30 HOW BTRY FDC - BTR 60	3150 m BACK IN 2ND MRB	47.50	50.50	65.50	2.31
31	ZPU-4 /#1	FRONT OF BDE HQ GROUP	49.80	52.80	67.80	2.5
32	ZPU-4/#2	50 m IN BACK OF BDE HQ GROUP	49.85	52.85	67.85	2.5
33	ZPU-4/#3	100 m IN BACK OF BDE HQ GRP	49.90	52.90	67.90	2.5
34	ZPU-4/#4	150 m IN BACK OF BDE HQ GRP	49.95	52.95	67.95	2.5
35	ZPU-4/#5	200 m IN BACK OF BDE HQ GRP	50.00	53.00	68.00	2.5
36	ZPU-4/#6	250 m IN BACK OF BDE HQ GRP	50.05	5[illegible].05	68.05	2.5
37	M1939 37mm(SP) ADA GUN #1	300 m IN BACK OF BDE HQ GRP	50.10	53.10	68.10	2.5
38	M1939 37mm(SP) ADA GUN #2	350 m IN BACK OF BDE HQ GRP	50.15	53.15	68.15	2.5
39	M1939 37mm(SP) ADA GUN #3	400 m IN BACK OF BDE HQ GRP	50.20	53.20	68.20	2.5

TARGET NUMBER	TARGET DESCRIPTION	POSITION IN ATTACK COLUMN	INITIAL RANGE TO SENSORS 1-3 (km)	INITIAL RANGE TO SENSORS 4-5 (km)	INITIAL RANGE TO EFOGM BATTERY (km)	TARGET HEIGHT (m)
40	M1939 37mm(SP) ADA GUN #4	450 m IN BACK OF BDE HQ GRP	50.25	53.25	68.25	2.5
41	BDE CDR BMP	500 m IN BACK OF BDE HQ GRP	50.30	53.30	68.30	2.15
42	BDE S3 BMP	550 m IN BACK OF BDE HQ GRP	50.35	53.35	68.35	2.15
43	ARTY MOBILE RECON POST "SMALL FRED"	800 m IN BACK OF BDE HQ GRP	50.60	53.60	68.60	2.15
44	ZU-23 (T) ADA GUN # 1	950 m IN BACK OF BDE HQ GRP	50.75	53.75	68.75	2.00
45	ZU-23 (T) ADA GUN # 2	1000 m IN BACK OF BDE HQ GRP	50.80	53.80	68.80	2.00
46	ZU-23 (T) ADA GUN # 3	1050 m IN BACK OF BDE HQ GRP	50.85	53.85	53.85	2.00
47	ZU-23 (T) ADA GUN # 4	1100 m IN BACK OF BDE HQ GRP	50.90	53.90	68.90	2.00
48	1st M46 130mm HOW(T) BTRY FDC BTR 60	2100 m IN BACK OF BDE HQ GRP	51.90	54.90	69.90	2.31
49	M46 130mm HOW(T) 1st BN TOC BTR 60	2450 m IN BACK OF BDE HQ GRP	52.25	55.25	70.25	2.31
50	2nd M46 130mm HOW(T) BTRY FDC BTR 60	2500 m IN BACK OF BDE HQ GRP	52.30	55.30	70.30	2.31
51	3rd M46 130mm HOW(T) BTRY FDC BTR 60	2850 m IN BACK OF BDE HQ GRP	52.65	55.65	70.65	2.31
52	4th M46 130mm HOW(T) BTRY FDC BTR 60	3250 m IN BACK OF BDE HQ GRP	53.05	56.05	71.05	2.31
53	M46 130mm HOW(T) 2nd BN TOC BTR 60	3600 m IN BACK OF BDE HQ GRP	53.40	56.40	71.40	2.31
54	5th M46 130mm HOW(T) BTRY FDC BTR 60	3650 m IN BACK OF BDE HQ GRP	53.45	56.45	71.45	2.31
55	6th M46 130mm HOW(T) BTRY FDC BTR 60	4000 m IN BACK OF BDE HQ GRP	53.80	56.80	71.80	2.31
56	1st BM-21 BTRY FDC	4400 m IN BACK OF BDE HQ GRP	54.20	57.20	72.20	2.89
57	BM-21 BN TOC	5750 m IN BACK OF BDE HQ GRP	54.55	57.55	72.55	2.89
58	2ND BM-21 BTRY FDC	5800 m IN BACK OF BDE HQ GRP	54.60	57.60	72.60	2.89

TARGET NUMBER	TARGET DESCRIPTION	POSITION IN ATTACK COLUMN	INITIAL RANGE TO SENSORS 1-3 (km)	INITIAL RANGE TO SENSORS 4-5 (km)	INITIAL RANGE TO EFOGM BATTERY (km)	TARGET HEIGHT (m)
59	3RD BM-21 BTRY FDC	6150 m IN BACK OF BDE HQ GRP	54.90	57.90	72.90	2.89
60	TK CO CDR #1 T-55	150 m IN BACK OF TK BN FRONT	57.45	60.45	75.45	2.20
61	TK BN CDR T-55	650 m IN BACK OF TK BN FRONT	57.90	60.90	75.90	2.20
62	ARTY MOBILE RECON POST "SMALL FRED"	700 m IN BACK OF TK BN FRONT	58.00	61.00	76.00	2.15
63	TK CO CDR #2 T-55	1000m IN BACK OF TK BN FRONT	58.25	61.25	76.25	2.20
64	TK CO CDR #3 T-55	1650 m IN BACK OF TK BN FRONT	58.90	61.90	76.90	2.20
65	MRC 1 CDR BMP	200 m IN BACK OF MRB FRONT	61.00	64.00	79.00	2.15
66	MRB CDR BMP	650 m IN BACK OF MRB FRONT	61.45	64.45	79.45	2.15
67	ARTY MOBILE RECON POST "SMALL FRED"	750 m IN BACK OF MRB FRONT	61.55	64.55	79.55	2.15
68	MRC 2 CDR BMP	1300 m IN BACK OF MRB FRONT	62.10	65.10	80.10	2.15
69	MRC 3 CDR BMP	1950 m IN BACK OF MRB FRONT	62.75	65.75	80.75	2.15

APPENDIX H. THE DYNTACS MODEL[1]

Any discussion of the DYNTACS equation must first consider the history of detection modeling. B.O. Koopman first published a report on target acquisition modeling for the U.S. Navy in 1946. In his report he defined detection as "...that event constituted by the observer's becoming aware of the presence and possibility of the position and even in some cases the motion of the target." [Ref. 2, pg. 67] There are several distinct areas of target acquisition. These include:

- Cueing Information, which provides the approximate area on the battlefield for continuing search (i.e., an explosion, gun flash, reflections).
- Detection means that an observer has decided that something within his field of view has some military value (e.g. he determines it's a man and not a deer).
- Classification occurs when the observer is able to distinguish between the type of target discovered (e.g. a wheeled vehicle versus a tracked vehicle).
- Recognition occurs when the observer is able to determine between a smaller variety of tracked vehicles (e.g. a tracked troop carrier versus a tank).
- Identification occurs when the observer is able to precisely identify the target (e.g., a BRDM versus a BTR-60P).

The continuous looking model was the second of Koopman's basic detection model paradigms. The continuous looking model is based on a detection rate function D(t), which is the probability of detecting a target in the short time interval t ,which is proportional to the length, Δ, of the time interval. The formula for this detection function is:

$$P(detect\ in\ [t,\ t + \Delta T]) = D(t) * \Delta T. \qquad (1)$$

[1] This discussion of the DYNTACS equation is paraphrased from Ref. 2, Chapter IV.

Assuming that the Detection function remains constant for all values of t, then for a longer period of time T, $T = N * \Delta T$, where N is the number of intermittent opportunities to detect a target, or "glimpses". Therefore, the probability of detection in a time period of length T is:

$$\begin{aligned} P(\text{Detect in length } T) &= 1 - P(\text{fail to detect in } N \text{ tries}) \\ &= 1 - (1 - D*\Delta T)^N \\ &= 1 - (1 - D*T/N)^N \end{aligned} \tag{2}$$

Taking the limit, as N approaches infinity, ΔT approaches 0, and $T = N*\Delta T$ held constant, this becomes

$$P(\text{Detect in length } T) = 1 - EXP(-D*T). \tag{3}$$

This equation is recognized as the cumulative distribution function (CDF) of the exponential probability distribution. This detection rate function can be used in both fixed time and event scheduled simulations.

The DYNTACS curve fit model was developed in conjunction with a set of field experiments conducted in the 1960's to provide good experimental data for detection rates as a function of several parameters. A "detection" within these experiments is the same as an "identification" listed above. The experiment has some limitations.

- All experiments were conducted during daylight at limited ranges (1.5 kilometers).
- Observers had restricted fields of view (30 degrees).
- Observers were stationary, and not mounted in vehicles.
- Observers used the naked eye for observation with no vision aids.

The experiments verified that the exponential distribution could be used for observed detection times, stationary targets, and that a constant detection rates were valid. The experimental data were used in regression models to compute detection rates D for various situations.

While the resulting detection rate functions is only valid for simulations which follow the experimental situation, it has been extended to ranges of 5 kilometers and for observers from vehicles. Using Equation (3), and solving for t yields:

$$t = ln\ (1 - P(Detection))/-D. \quad (4)$$

The value for P(Detection) can easily be simulated using a Monte Carlo draw from a generator of Uniform(0,1) random variables. The DYNTACS experiment provides the value of D, where

$$D = P_k * \{-0.003 + [\ 1.088 / DENOMINATOR]\ \}, \quad (5)$$

and

$$DENOMINATOR = 1.453 + \tau*(0.05978 + 2.188R^2 - 0.5038*CV). \quad (6)$$

Observation conditions for DENOMINATOR are given by

- τ = terrain complexity code. This is equivalent to the number of potential avenues of approach for the enemy into the battle area.
- R = apparent range in kilometers. The apparent range is the range at which the image of a fully exposed M60 tank would be the same height as an image for the current target. R = (actual range * M60 height) / (target height * percent visible). Percent visible is the quantity target height minus the average vegetation height in the area, divided by the target height.
- CV = crossing velocity in meters per second. This is the perpendicular component of the target velocity relative to the observer target line.
- P_k = the probability the observer is looking in the 30 degree search sector which contains the target.

Target acquisition within the simulation model by the function *TimeToAcquire* which uses the DYNTACS equation. *TimeToAcquire* is called by the sub-routine *Search* within the simulation model sub-programs *MASTERTIMER* and *MASTERTIMER2* The values above are provided by the user within the input data file. Once a value for *D* is calculated by *TimeToAcquire*, this value is substituted into equation (4) within the function, which calculates the time of detection for that specific target. Once *Search* has looped over all possible targets for a specific FO, the detected target with the minimum time of acquisition becomes the acquired target for that FO, and is forwarded for further processing by the simulation model.

APPENDIX I. SAMPLE OUTPUT DATA FILE

Table 6 below contains a portion of an output data file for a non-digitized replication, after formatting in a spreadsheet program.

	Detection Time	CFF arrives @ BDE	CFF arrives @ FSO	FSO starts processing CFF	CFF arrives @ LNO	LNO starts processing CFF	CFF arrives to Battery	Battery Processing Complete	LAL / DUD Missile Time	Launch Time	Impact Time (If <> 999.9)
(O,T)	**State 1**	**State 2**	**State 3**	**State 4**	**State 5**	**State 6**	**State 7**	**State 8**	**State 9**	**State 10**	**State 11**
(1, 1)	24.695	24.985	26.264	999.9	999.9	999.9	999.9	999.9	999.9	999.9	999.9
(1, 2)	12.5	12.693	13.723	999.9	999.9	999.9	999.9	999.9	999.9	999.9	999.9
(1, 3)	92.422	92.655	93.693	93.846	94.574	94.795	96.18	98.693	999.9	122.165	124.42
(1, 4)	94.782	95.052	96.013	96.013	96.638	97.276	98.111	100.604	999.9	122.668	124.90
(1, 5)	97.76	98.018	98.949	99.992	100.574	102.925	104.3	106.551	999.9	122.726	124.97
(1, 6)	109.912	110.124	111.101	999.9	999.9	999.9	999.9	999.9	999.9	999.9	999.9
(1, 7)	112.806	113.06	114.235	999.9	999.9	999.9	999.9	999.9	999.9	999.9	999.9
(1, 8)	100.703	100.993	102.156	999.9	999.9	999.9	999.9	999.9	999.9	999.9	999.9
(1, 9)	107.302	107.549	108.457	999.9	999.9	999.9	999.9	999.9	999.9	999.9	999.9
(1,10)	90.042	90.267	91.314	91.314	92.046	92.046	93.187	95.338	999.9	124.511	126.73
(1,11)	106.211	106.44	107.295	107.367	107.899	110.933	111.982	114.235	999.9	124.226	126.47
(1,12)	118.809	119.02	120.202	999.9	999.9	999.9	999.9	999.9	999.9	999.9	999.9
(1,13)	105.655	105.922	107.237	999.9	999.9	999.9	999.9	999.9	999.9	999.9	999.9
(1,14)	95.73	95.971	96.89	97.256	97.936	99.056	100.081	103.185	999.9	124.127	126.41

Table 6. Example Output Data File from Non-Digitized Replication Run

Output tables similar to Table 6 were produced for each replication of the simulation model. From these tables, the time a CFF from a specific FO on a specific target (enumerated in each row) arrive at various processing stages can be seen. "999.9" is the default value that the data array **OutData** (discussed in Chapter 3) is initialized to at the beginning of each replication. For example, the CFF from FO 1 on Target 2 (shown in row four) indicates that Target 2 was detected by FO 1 (seen under State 1) at 12.5 minutes into the battle. The CFF reached BDE (time under State 2) at 12.69 minutes in the battle, and that the FSO received the CFF (time under State 3) at 13.72 minutes into the battle. From that point, all remaining column values are "999.9", indicating that the CFF never went beyond the FSO. This could have been because the total CFF processing time was too great, or that the FSO had previously processed a CFF on that target from another FO.

In order to obtain total CFF processing time, values in State 8 (Battery completes CFF processing) are subtracted from values in State 1 (Detection Time),and the total CFF processing time is obtained. Likewise, by subtracting the time under State 4 from State 3, or the time under State 6 from State 5, the time a CFF spent in the FSO or LNO queue can be found. Similar processing of all CFF was conducted for both digitized and non-digitized replications. These data values were then used to compute the statistics for CFF processing time and LNO and FSO queue time, which are used in this thesis. A summary of all CFF processing times is located in Appendix N.

APPENDIX J. LOGNORMAL DISTRIBUTION FIT, NON-DIGITIZED, BASE CASE DATA

The following figures depict the AGSS analysis of the non-digitized, base case data to the lognormal distribution.

```
                    ANALYSIS OF LOGNORMAL DISTRIBUTION FIT

DATA         :  DIGIT   .
SELECTION    :  ALL
X AXIS LABEL:  DIGIT
SAMPLE SIZE :  1200
CENSORING    :  NONE
FREQUENCIES :  1
EST. METHOD :  MAXIMUM LIKELIHOOD
CONF METHOD :  EXACT

                   CONF. INTERVALS    COVARIANCE MATRIX OF
                    (95 PERCENT)      PARAMETER ESTIMATES
PARAMETER  ESTIMATE  LOWER    UPPER      MU          SIGMA
MU         0.37196  0.36692  0.37699    6.5905E-6 0.0000E0
SIGMA      0.088931 0.085545 0.092678   0.0000E0  3.2953E-6
LOG LIKELIHOOD FUNCTION AT MLE = 754.81

            SAMPLE     FITTED                    GOODNESS OF FIT TESTS
MEAN     :  1.4564      1.4563                 CHI-SQUARE :  26.665
STD DEV :  0.1326      0.12977                  DEG FREED:   6
SKEWNESS:  0.82888     0.26803                   SIGNIF   :  0.00016727
KURTOSIS:  5.1548      3.128                   KOLM-SMIRN :  0.028479
• BASED ON MIDPOINTS OF FINITE INTERVALS         SIGNIF   :  0.28469
                                               CRAMER-V M :  0.16116
PERCENTILES   SAMPLE     FITTED                  SIGNIF   :   > .15
     5:      1.2615    1.253′                  ANDER-DARL :  1.2424
    10:      1.3015    1.2943                    SIGNIF   :   > .15
    25:      1.364     1.3662
    50:      1.447     1.4506                  KS, AD, AND CV SIGNIF. LEVELS NOT
    75:      1.5345    1.5402                  EXACT WITH ESTIMATED PARAMETERS.
    90:      1.619     1.6257
    95:      1.6795    1.6791                  NOTE:  A SMALL SIGNIFICANCE LEVEL
                                               (EG. P≤.01) INDICATES LACK OF FIT

         CHI-SQUARE GOODNESS OF FIT TABLE

LOWER   UPPER   OBS    EXP      O-E     ((O-E)•2)÷E
-INF.   1.1895   5    15.401  -10.401    7.0241
1.1895  1.281   77    81.89    -4.8899   0.29199
1.281   1.3725 247   223.05    23.952    2.572
1.3725  1.464  333   329.19     3.806    0.044004
1.464   1.5555 295   291.12     3.8782   0.051665
1.5555  1.647  156   167.39   -11.386    0.77452
1.647   1.7385  56    66.913  -10.913    1.7798
1.7385  1.83    17    19.659   -2.6588   0.3596
1.83    +INF.   14     5.3876   8.6125  13.768
TOTAL          1200 1200                26.665
```

Figure 19. Lognormal Distribution Graphical Analysis

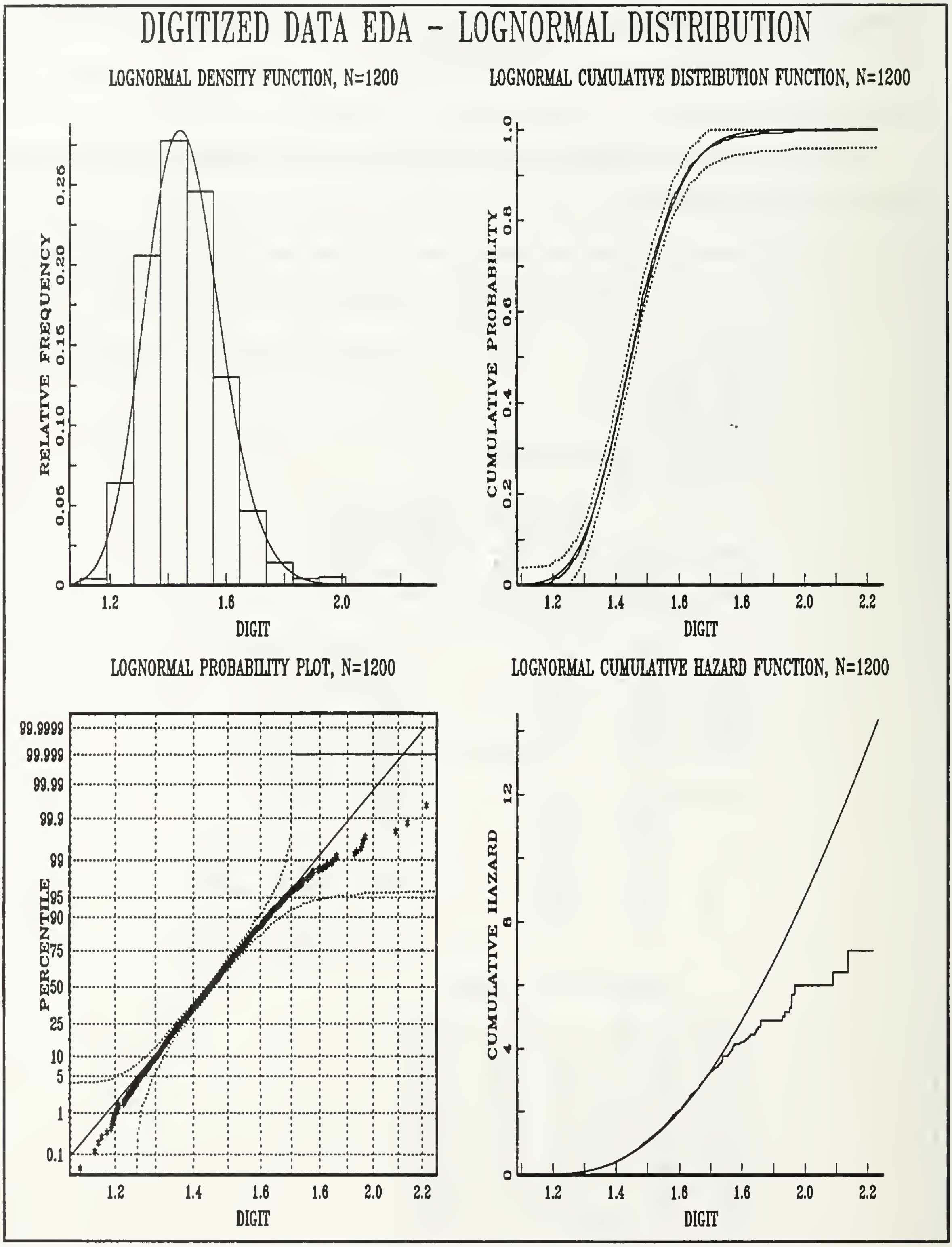

Figure 20. Lognormal Distribution Data Analysis

APPENDIX K. WEIBULL AND BETA DISTRIBUTION COMPARISONS, NON-DIGITIZED, BASE CASE + 25% DATA

The following figures depict the AGSS analysis of the non-digitized, base case + 25% data for the Weibull and Beta distributions.

ANALYSIS OF WEIBULL DISTRIBUTION FIT

DATA : NONDIGIT
SELECTION : ALL
X AXIS LABEL: NONDIGIT
SAMPLE SIZE : 1199
CENSORING : NONE
FREQUENCIES : 1
EST. METHOD : MAXIMUM LIKELIHOOD
CONF METHOD : ASYMPTOTIC NORMAL APPROXIMATION

		CONF. INTERVALS (95 PERCENT)		COVARIANCE MATRIX OF PARAMETER ESTIMATES	
PARAMETER	ESTIMATE	LOWER	UPPER	C	α
C (SHAPE)	2.7083	2.5859	2.8307	0.0038977	0.0042827
α (SCALE)	19.292	18.867	19.717	0.0042827	0.047025

LOG LIKELIHOOD FUNCTION AT MLE = -3993.4

	SAMPLE	FITTED
MEAN :	17.107	17.158
STD DEV :	6.9463	6.8343
SKEWNESS:	0.16079	0.64783
KURTOSIS:	2.0611	1.2917

• BASED ON MIDPOINTS OF FINITE INTERVALS

PERCENTILES	SAMPLE	FITTED
5:	6.549	6.4429
10:	7.306	8.4044
25:	11.052	12.178
50:	16.875	16.85
75:	22.646	21.765
90:	26.827	26.249
95:	28.561	28.928

GOODNESS OF FIT TESTS

CHI-SQUARE :	61.689
DEG FREED:	10
SIGNIF :	1.7336E-9
KOLM-SMIRN :	0.053485
SIGNIF :	0.0020983
CRAMER-V M :	0.84601
SIGNIF :	< .01
ANDER-DARL :	6.8602
SIGNIF :	< .01

KS, AD, AND CV SIGNIF. LEVELS NOT EXACT WITH ESTIMATED PARAMETERS.

NOTE: A SMALL SIGNIFICANCE LEVEL (EG. P≤.01) INDICATES LACK OF FIT

CHI-SQUARE GOODNESS OF FIT TABLE

LOWER	UPPER	OBS	EXP	O-E	((O-E)•2)÷E
-INF.	7.4723	127	88.448	38.552	16.804
7.4723	9.963	101	95.981	5.0193	0.26248
9.963	12.454	124	131.34	-7.3403	0.41023
12.454	14.945	130	156.6	-26.595	4.5166
14.945	17.435	152	166.08	-14.078	1.1933
17.435	19.926	130	158.07	-28.065	4.9831
19.926	22.417	115	135.42	-20.417	3.0782
22.417	24.908	136	104.42	31.579	9.5503
24.908	27.398	92	72.338	19.662	5.3442
27.398	29.889	62	44.888	17.112	6.5235
29.889	32.38	22	24.859	-2.8594	0.32889
32.38	34.871	7	12.237	-5.2372	2.2414
34.871	+INF.	1	8.3334	-7.3334	6.4534
TOTAL		1199	1199		61.689

Figure 21. Weibull Distribution Data Analysis

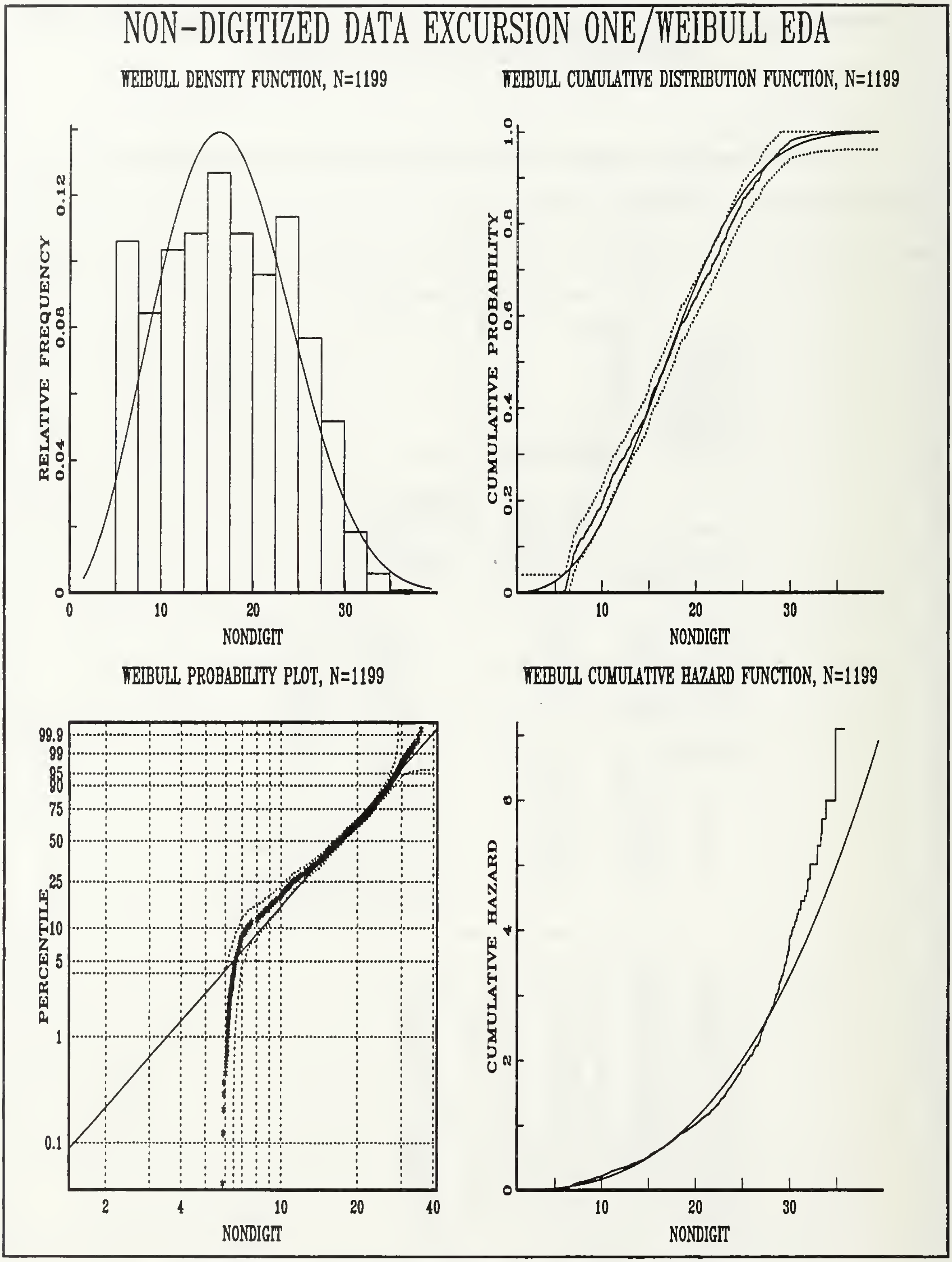

Figure 22. Weibull Distribution Graphical Analysis

ANALYSIS OF BETA DISTRIBUTION FIT

DATA : NORMNONDIGIT
SELECTION : ALL
X AXIS LABEL: NORMNONDIGIT
SAMPLE SIZE : 1199
CENSORING : NONE
FREQUENCIES : 1
EST. METHOD : MAXIMUM LIKELIHOOD
CONF METHOD : ASYMPTOTIC NORMAL APPROXIMATION

		CONF. INTERVALS (95 PERCENT)		COVARIANCE MATRIX OF PARAMETER ESTIMATES	
PARAMETER	ESTIMATE	LOWER	UPPER	P	Q
P	2.7297	2.5199	2.9396	0.011457	0.010378
Q	2.9243	2.6982	3.1504	0.010378	0.013307

LOG LIKELIHOOD FUNCTION AT MLE = 295.01

	SAMPLE	FITTED
MEAN :	0.47874	0.4828
STD DEV :	0.19439	0.19372
SKEWNESS:	0.16079	0.046415
KURTOSIS:	2.0611	2.3095

* BASED ON MIDPOINTS OF FINITE INTERVALS

PERCENTILES	SAMPLE	FITTED
5:	0.18328	0.16823
10:	0.20446	0.22422
25:	0.30929	0.33691
50:	0.47225	0.48067
75:	0.63376	0.62662
90:	0.75076	0.74466
95:	0.79929	0.80478

GOODNESS OF FIT TESTS

CHI-SQUARE :	19.458
DEG FREED:	9
SIGNIF :	0.021566
KOLM-SMIRN :	0.046718
SIGNIF :	0.010666
CRAMER-V M :	0.4386
SIGNIF :	< .10
ANDER-DARL :	4.1562
SIGNIF :	< .01

KS, AD, AND CV SIGNIF. LEVELS NOT EXACT WITH ESTIMATED PARAMETERS.

NOTE: A SMALL SIGNIFICANCE LEVEL (EG. P≤.01) INDICATES LACK OF FIT

CHI-SQUARE GOODNESS OF FIT TABLE

LOWER	UPPER	OBS	EXP	O-E	((O-E)*2)÷E
-INF.	0.20911	127	101.6	25.397	6.3483
0.20911	0.27882	101	96.561	4.4395	0.20411
0.27882	0.34852	124	123.75	0.25514	0.00052607
0.34852	0.41822	130	142.46	-12.457	1.0893
0.41822	0.48793	152	150.84	1.1559	0.0088572
0.48793	0.55763	130	149.06	-19.063	2.4378
0.55763	0.62733	115	136.29	-21.293	3.3265
0.62733	0.69704	136	115.26	20.739	3.7316
0.69704	0.76674	92	87.934	4.066	0.18801
0.76674	0.83644	62	57.803	4.197	0.30474
0.83644	0.90615	22	29.294	-7.2936	1.816
0.90615	+INF.	8	8.1435	-0.14352	0.0025292
TOTAL		1199	1199		19.458

Figure 23. Beta Distribution Data Analysis

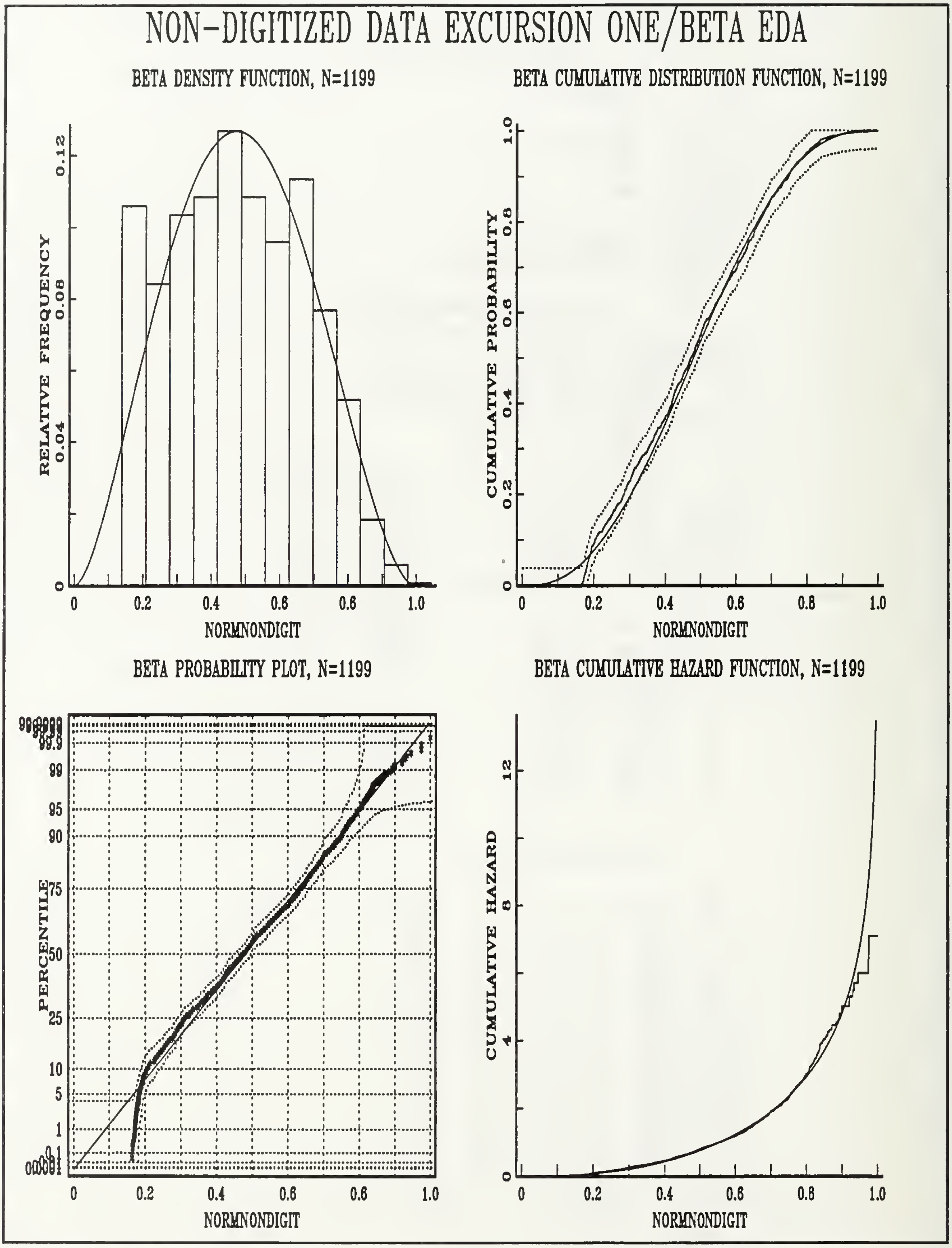

Figure 24. Beta Distribution, Graphical Analysis

APPENDIX L. LOGNORMAL DISTRIBUTION COMPARISON, DIGITIZED, BASE CASE DATA

The following figures depict the AGSS analysis of the digitized, base case data for the lognormal distribution.

ANALYSIS OF LOGNORMAL DISTRIBUTION FIT

DATA : DIGIT
SELECTION : ALL
X AXIS LABEL: DIGIT
SAMPLE SIZE : 1200
CENSORING : NONE
FREQUENCIES : 1
EST. METHOD : MAXIMUM LIKELIHOOD
CONF METHOD : EXACT

		CONF. INTERVALS (95 PERCENT)		COVARIANCE MATRIX OF PARAMETER ESTIMATES	
PARAMETER	ESTIMATE	LOWER	UPPER	MU	SIGMA
MU	0.37196	0.36692	0.37699	6.5905E-6	0.0000E0
SIGMA	0.088931	0.085545	0.092678	0.0000E0	3.2953E-6

LOG LIKELIHOOD FUNCTION AT MLE = 754.81

	SAMPLE	FITTED
MEAN :	1.4564	1.4563
STD DEV :	0.1326	0.12977
SKEWNESS:	0.82888	0.26803
KURTOSIS:	5.1548	3.128

* BASED ON MIDPOINTS OF FINITE INTERVALS

PERCENTILES	SAMPLE	FITTED
5:	1.2615	1.253'
10:	1.3015	1.2943
25:	1.364	1.3662
50:	1.447	1.4506
75:	1.5345	1.5402
90:	1.619	1.6257
95:	1.6795	1.6791

GOODNESS OF FIT TESTS

CHI-SQUARE :	26.665
DEG FREED:	6
SIGNIF :	0.00016727
KOLM-SMIRN :	0.028479
SIGNIF :	0.28469
CRAMER-V M :	0.16116
SIGNIF :	> .15
ANDER-DARL :	1.2424
SIGNIF :	> .15

KS, AD, AND CV SIGNIF. LEVELS NOT EXACT WITH ESTIMATED PARAMETERS.

NOTE: A SMALL SIGNIFICANCE LEVEL (EG. P≤.01) INDICATES LACK OF FIT

CHI-SQUARE GOODNESS OF FIT TABLE

LOWER	UPPER	OBS	EXP	O-E	((O-E)*2)÷E
-INF.	1.1895	5	15.401	-10.401	7.0241
1.1895	1.281	77	81.89	-4.8899	0.29199
1.281	1.3725	247	223.05	23.952	2.572
1.3725	1.464	333	329.19	3.806	0.044004
1.464	1.5555	295	291.12	3.8782	0.051665
1.5555	1.647	156	167.39	-11.386	0.77452
1.647	1.7385	56	66.913	-10.913	1.7798
1.7385	1.83	17	19.659	-2.6588	0.3596
1.83	+INF.	14	5.3876	8.6125	13.768
TOTAL		1200	1200		26.665

Figure 25. Lognormal Distribution Data Analysis

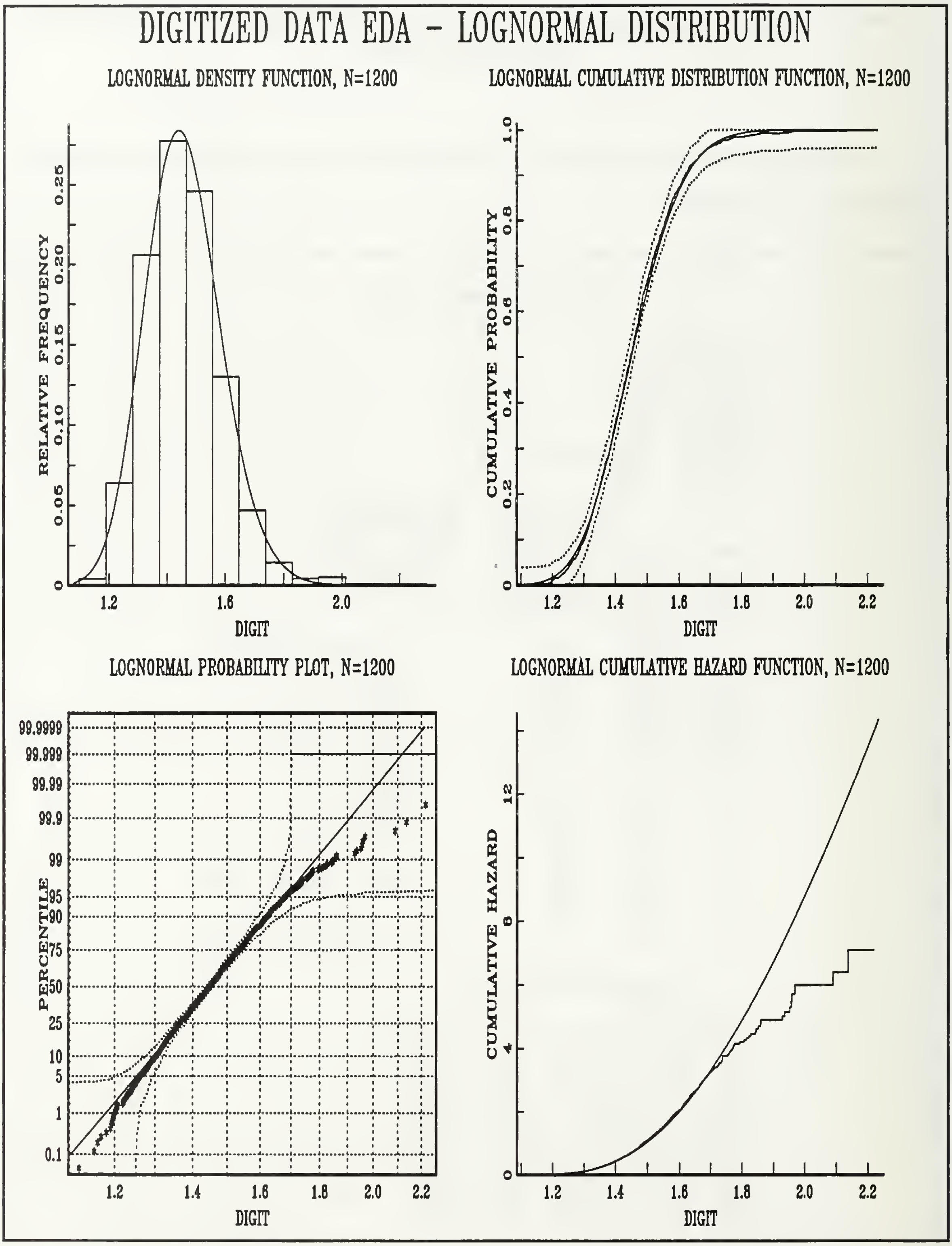

Figure 26. Lognormal Distribution Graphical Analysis

APPENDIX M. LOGNORMAL DISTRIBUTION COMPARISON, DIGITIZED, BASE CASE + 25% DATA

The following figures depict the AGSS analysis of the digitized, base case + 25% data for the lognormal distribution.

ANALYSIS OF LOGNORMAL DISTRIBUTION FIT

DATA : DIGIT
SELECTION : ALL
X AXIS LABEL: DIGIT
SAMPLE SIZE : 1200
CENSORING : NONE
FREQUENCIES : 1
EST. METHOD : MAXIMUM LIKELIHOOD
CONF METHOD : EXACT

PARAMETER	ESTIMATE	CONF. INTERVALS (95 PERCENT) LOWER	UPPER	COVARIANCE MATRIX OF PARAMETER ESTIMATES MU	SIGMA
MU	0.5554	0.55096	0.55984	5.1182E-6	0.0000E0
SIGMA	0.07837	0.075386	0.081672	0.0000E0	2.5591E-6

LOG LIKELIHOOD FUNCTION AT MLE = 686.38

	SAMPLE	FITTED
MEAN :	1.748	1.748
STD DEV :	0.13836	0.1372
SKEWNESS:	0.50372	0.23596
KURTOSIS:	4.6185	3.0991

* BASED ON MIDPOINTS OF FINITE INTERVALS

PERCENTILES	SAMPLE	FITTED
5:	1.533	1.5318
10:	1.5755	1.5761
25:	1.6535	1.653
50:	1.7425	1.7426
75:	1.835	1.8372
90:	1.92	1.9268
95:	1.975	1.9825

GOODNESS OF FIT TESTS

CHI-SQUARE : 2.3033
DEG FREED: 5
SIGNIF : 0.80579
KOLM-SMIRN : 0.010715
SIGNIF : 0.99913
CRAMER-V M : 0.016625
SIGNIF : > .15
ANDER-DARL : 0.17351
SIGNIF : > .15

KS, AD, AND CV SIGNIF. LEVELS NOT EXACT WITH ESTIMATED PARAMETERS.

NOTE: A SMALL SIGNIFICANCE LEVEL (EG. P≤.01) INDICATES LACK OF FIT

CHI-SQUARE GOODNESS OF FIT TABLE

LOWER	UPPER	OBS	EXP	O-E	((O-E)*2)÷E
-INF.	1.498	28	32.151	-4.151	0.53594
1.498	1.605	150	144.13	5.8722	0.23925
1.605	1.712	308	316.3	-8.2956	0.21757
1.712	1.819	365	356.9	8.0957	0.18363
1.819	1.926	235	229.48	5.525	0.13302
1.926	2.033	88	91.502	-3.5016	0.134
2.033	2.14	20	24.284	-4.2844	0.75587
2.14	+INF.	6	5.2603	0.73967	0.10401
TOTAL		1200	1200		2.3033

Figure 27. Lognormal Distribution Data Analysis

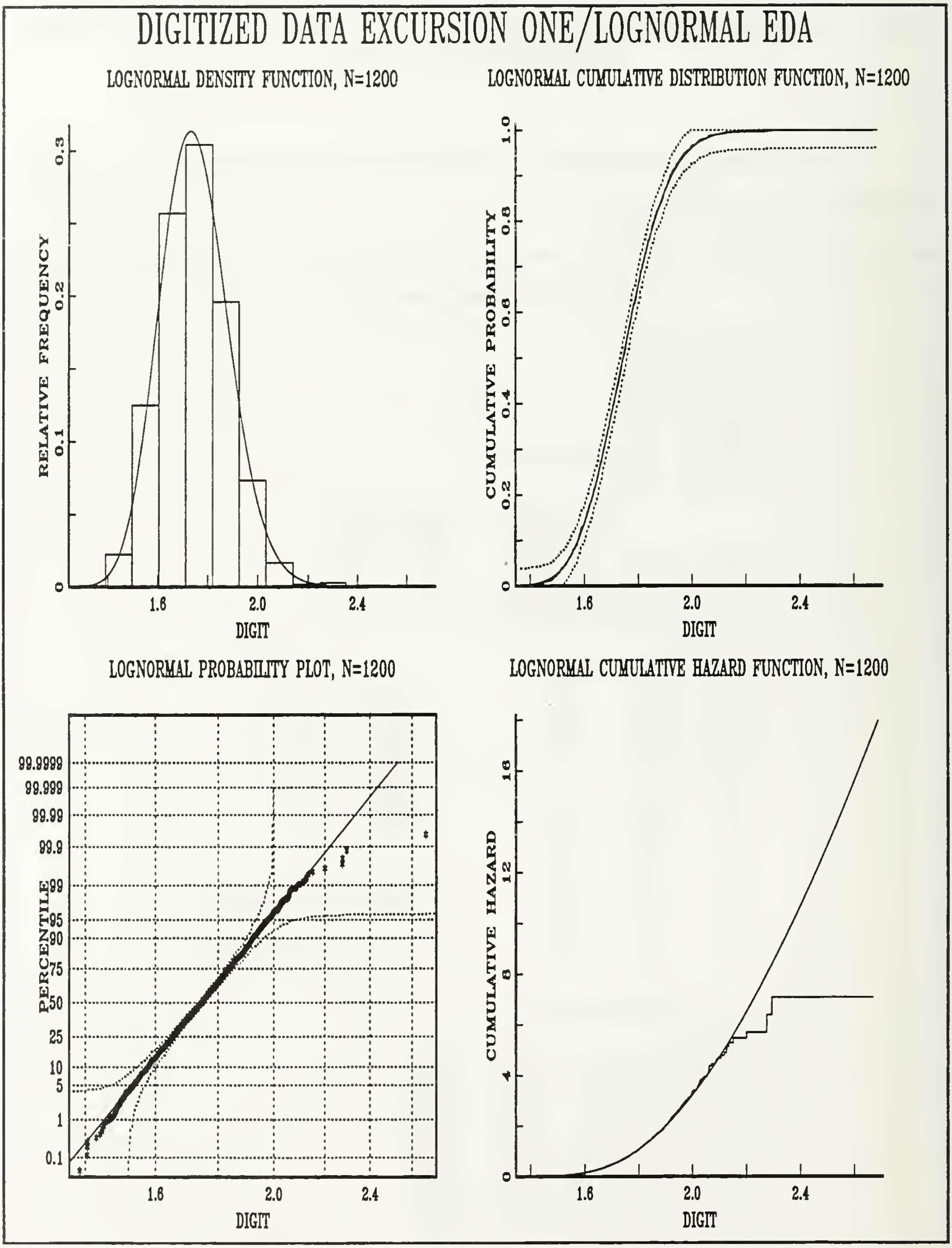

Figure 28. Lognormal Distribution Graphical Analysis

APPENDIX N. RUNS MATRIX WITH RESULTS

Table 7 contains the results of all replication runs of the simulation model showing mean and standard deviation times for CFF processing and times in the FSO or LNO queues.

Run Number	Type Run (Digitized / Non-Digitized)	Number of Targets	Number of Missiles	Processing Times (Base / Base + 25%)	Total Stnd Dev	Number of Reps	FSO Mean	FSO Stnd Dev	LNO Mean	LNO Stnd Dev	Total Mean
5	Digitized	35	48	Base	0.1371	10	N/A	N/A	N/A	N/A	1.4506
1	Digitized	69	48	Base	0.1326	25	N/A	N/A	N/A	N/A	1.4564
25	Digitized	69	100	Base	0.1467	10	N/A	N/A	N/A	N/A	1.4636
6	Digitized	35	48	Base + 25%	0.1482	10	N/A	N/A	N/A	N/A	1.7451
2	Digitized	69	48	Base + 25%	0.1384	25	N/A	N/A	N/A	N/A	1.7480
26	Digitized	69	100	Base + 25%	0.1514	10	N/A	N/A	N/A	N/A	1.7487
31	Non-Digitized	15	48	Base	0.3444	10	0.0256	0.0986	0.0295	0.0926	5.0578
29	Non-Digitized	20	48	Base	0.5322	10	0.0769	0.2466	0.1161	0.2420	5.1915
9	Non-Digitized	24	48	Base	0.6210	10	0.0971	0.2324	0.1280	0.2808	5.4714
11	Non-Digitized	30	48	Base	0.7470	10	0.1197	0.2564	0.2488	0.5058	5 6359
7	Non-Digitized	35	48	Base	0.2243	10	0.1250	0.2573	0.2807	0.4667	5.6874
13	Non-Digitized	40	48	Base	2.1456	10	0.3906	0.6074	1.2088	1.7646	6.8564
15	Non-Digitized	45	48	Base	1.9638	10	0.3776	0.5656	1.2676	1.6027	6.8980
17	Non-Digitized	50	48	Base	2.1391	10	0.4482	0.5867	1.5046	1.7710	7.2438
19	Non-Digitized	55	48	Base	2.3521	10	0.7663	0.9135	1.6943	1.7904	7.5671
21	Non-Digitized	60	48	Base	3.6617	10	1.1042	1.4295	2.9324	3.1230	8.9447
23	Non-Digitized	65	48	Base	3.8119	10	1.6100	1.8329	3.8926	3.4501	10.0330
3	Non-Digitized	69	48	Base	3.4576	25	1.3979	1.5473	3.1259	2.8836	9.3282
27	Non-Digitized	69	100	Base	7.4668	10	6.5449	7.8415	7 2827	5.7021	15.0934
33	Non-Digitized	69	48	Base	4 1215	10	1.6008	1.7903	3 8804	3.2410	9.9547
32	Non-Digitized	15	48	Base + 25%	0.5203	10	0.0519	0.1615	0.1133	0.2621	6.3229
30	Non-Digitized	20	48	Base + 25%	1.0051	10	0.1466	0.3364	0.3325	0.7551	6.6442
10	Non-Digitized	24	48	Base + 25%	0.7234	10	0.1076	0.2536	0.2397	0.4885	6.8106
12	Non-Digitized	30	48	Base + 25%	1.4349	10	0.1884	0.3626	0.7106	1.1906	7.3612
8	Non-Digitized	35	48	Base + 25%	2.0650	10	0.2687	0.4531	1.2544	1.7734	7.9922
14	Non-Digitized	40	48	Base + 25%	3.1151	10	0.5135	0.7874	2.4311	2.7111	9.3109
16	Non-Digitized	45	48	Base + 25%	4.0531	10	1.5298	1.7339	3.9750	3.2587	11.5476
18	Non-Digitized	50	48	Base + 25%	4.6752	10	1.6551	2.1131	4.7369	4.0313	12.1109
20	Non-Digitized	55	48	Base + 25%	4.9820	10	2.1787	3.0220	5.1350	4.2567	12.4411
22	Non-Digitized	60	48	Base + 25%	6.7624	10	3.5437	3.4347	8.0908	5.6885	16.2878
24	Non-Digitized	65	48	Base + 25%	6.5043	10	3.6628	3.8570	8.7313	5.8609	16.6162
4	Non-Digitized	69	48	Base + 25%	6.9463	25	4.6083	4.1705	8.4778	5.7103	17.1068
28	Non-Digitized	69	100	Base + 25%	10.3247	10	13.4135	11.8320	11.9900	8.0394	21.8574
34	Non-Digitized	69	48	Base + 25%	6.7437	10	4.0994	3 9114	7.1813	5.5941	15.8407

Table 7. Run Design Matrix with Results

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